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DEVELOPMENT AND DEMONSTRATION OF MANUFACTURING PROCESSES FOR FABRICATING GRAPHITE/LARC-160 POLYIMIDE STRUCTURAL ELEMENTS

7TH QUARTERLY PROGRESS REPORT

DECEMBER 16, 1979 THROUGH MARCH 15, 1980

CONTRACT NAS1-15371

PART IV, PARAGRAPH B

JULY 1980

Rockwell International
Space Transportation System
Development & Production Division
Space Systems Group

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FOREWORD

This quarterly technical report was prepared by the Space Systems Group of Rockwell International, under contract NAS1-15371 for the Materials Application Branch, Materials Division, NASA Langley Research Center, Hampton, Virginia. Mr. Robert M. Baucom is the NASA Program Manager.

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1.0 INTRODUCTION

Contract NAS1-15371 is the third NASA/LaRC program of Project CAST", Composites for Advanced Space Transporation Systems. The first progra utilized NR150-B2 polyimide resin and was conducted by General Dynamic , San Diego. PMR-15 polyimide resin was the subject of the second program conducted by Boeing Aerospace Company. The third program, NAS1-15371, utilizing LARC-160 polyimide resin, was awarded to the Space Systems Group of Rockwell International.

The three programs have as a common objective, the developmnet and demonstration of technologies to implement structural application of graphite polyimide for 316C (600F) service environment. Technologies evolved from these programs will be transferred to Space Shuttle structural flight hardware according weight savings not attainable with conventional composite materials.

2.0 PROGRAM PLAN

The program is divided into two parts: process development and demonstration components. Each consists of several tasks. The program schedule is presented in Figure 1. The following briefly describes the objective of each task:

Part 1. Process Development

Task (a) - Develop a quality assurance program including specification for Celion/ LARC-160 polyimide materials, quality control of materials and processes, including studies of the effects of monomer and/or polymer variables and prepreg variables on the processibility of Celion/LARC-160 prepreg and on the mechanical properties of test specimens fabricated from the prepreg, and NDI of fabricated components.

Task (b) - Develop processes for fabricating laminates, hat and "I" stiffeners, honeycomb core panels, and chopped fiber moldings.

Task (c) - Fabricate specimens and conduct tests to qualify the processes for fabrication of demonstration components.

Part 2. Demonstration Components

Task (d) - Fabricate and NDI three (3) laminates 61x122-cm (24x48-in.) with 0, $\pm$ 45° lay up symmetrical about the neutral axis. Laminate thickness will be 0.08cm, 0.15cm, and 0.32cm (0.030 in., 0.060 in., and 0.125 in.).

Task (e) - Fabricate and NDI three (3) secondarily bonded hat-stiffened skin-stringer panels 23cm (9in.) wide x 122cm (48 in.) long with 3 lengthwise stiffeners.

Task (f) - Fabricate six (6) honeycomb core panels 25.4x25.4-cm (10x10-in.) with 0.15cm (0.060 in.) thick face sheets with 0^{o}, 90^{o}, layup symmetrical about the neutral axis of the panel. The honeycomb core will be 2.54cm (1 in.) thick.

Task (g) - Fabricate six (6) chopped fiber moldings according to a specimen design mutually agreeable to Contractor and Contracting Officer's technical representative.

Task (h) - Fabricate a representative component of a Space Shuttle aft body flap that is mutually agreeable to the Contractor and Contracting Officer's technical representative.

3.0 PROGRAM PROGRESS

3.1 TASK (a) - QUALITY ASSURANCE PROGRAM

3.1.1 Chemical Characterization of LARC-160 Polyimide Resin

Several additional batches of Hexcel LARC-160 intermediate esters have been analyzed by liquid chromatography (HPLC) during this quarter. These include two production scale and three Variables Study lots of material. Identification of these and all previous Hexcel intermediate ester batches studies is given in Table 1.

The experimental HPLC procedure used to analyze the intermediate ester mixture has been discussed in previous reports. The separation achieved by this method is shown in Figure 2 for a production scale batch of Hexcel intermediate ester. Analysis of the chromatograms is that described previously in which the relative concentration of a given component is expressed as the percent area of that peak relative to the total peak area. The results for five new intermediate ester batches have been added to data previously reported. The composition of these new materials compared to earlier ones will be discussed in terms of several of the major ingredients.

BTDA Anhydride

The concentration variation in unesterified BTDA anhydride in Hexcel intermediate ester batches is shown in Figure 3. Two significant differences are noted for the recent lots of material. First, production scale batches G (23245, Cut 2) and H (23245, Cut 5) show no unreacted BTDA anhydride. This is in contract to the previous production scale batches which contained around four peak area percentage of this ingredient. The second difference is the large increase in BTDA anhydride content of the last three Variables Study batches (Runs 15, 16A, and 16).

BTDA Monoethyl Ester

The peak area percentage of one of the two BTDA monoethyl ester isomers is plotted in Figure 4. The more complete esterification discussed above for the last two production scale batches compared to previous ones is also clearly reflected in the low BTDA monoethyl ester levels of these two materials. The final three batches for the Variables Study show a substantial increase in monoethyl ester similar to that observed for BTDA anhydride in Figure 3. The trends in concentration of BTDA anhydride and monoethyl ester correlate closely since both relate to incomplete esterification of BTDA with Fotocol.

NA Monoethyl Ester

The relative concentration of the NA endcapper is plotted in Figure 5. Batch H (23245, Cut 5) shows a higher level of NA endcapper than other production lots of intermediate ester. The absolute amount. however, is at most only a few percent.

BTDA Diethyl Ester

The relative variation in one isomer of this component is shown in Figure 6. The increase in Batches G and H and decrease in the last three Variables Study materials is a result of changes in monoethyl ester content. For example, when there is little BTDA monoethyl ester present, such as in Batches G and H, then the relative amount of diethyl ester increases.

BTDA Triethyl Ester

The level of this compound in the Hexcel intermediate ester batches is shown in Figure 7. The amounts present in the new materials analyzed is very small as observed for previous ester mixtures.

NA Diethyl Ester

The variation in this minor component is shown in Figure 8. Its presence, like BTDA triethyl ester, is an indicator of excess cooking of the intermediate ester mixtures. The low levels detected should have little influence on resin processing or cure behavior.

Intermediate Ester Quality Control

The data for the final Variables Study batches and two additional production scale lots of intermediate ester show a wide discrepancy in extent of BTDA esterification. BTDA anhydride and monoethyl ester levels vary widely among the Hexcel materials. Although these variations have not thus far been associated with problems in processing or laminate properties it would be desirable to produce a more uniform intermediate ester mixture.

3.1.2 Unidirectional Prepreg

3.1.2.1 Production Prepreg

Prepreg batches 23328 and 23451, 30.48cm (12.0 inches) wide continuous tape and nominal 152 grams/m^2 areal fiber weight, were received from Hexcel. The material was designated for use in fabrication of hat-stiffened skin/stringer and sandwich panels in Task (e) and (c). Overall quality, cosmetic, tack, and drape, of both batches was very good. There was no exudation of resin from roll edges as seen in earlier batches. Visually, fiber and resin distributional control appeared good and tape surfaces were very smooth. Prepreg property tests performed on material within the first few feet from the start of each roll, however, showed the same lack of fiber and resin distributional control experienced in earlier batches. Detailed prepreg physical properties are presented in Table 2.

Composite quality verification testing laminate panels EX223 (11 plies) and EX224 (14 plies) from prepreg batch 23328R3 and panel EX237 (11 plies) from batch 23451 were fabricated to the standard two stage imidizing and cure process described in the 5th Quarterly report and updated in Appendix A. NDI C-scan tests resulted in 100% transmission through all panels as shown in Figures 9, 10 and 11. Panel EX237 was destroyed in postcure when the oven over ran to approximately 505C (950°F). This panel was replaced with EX254 (11 plies) from batch 23451. As shown in Figure 12, 100% transmission was obtained in NDI C-scan. Pertinent physical and mechanical properties of laminate panels are presented in Table 3.

3.1.2.2 Resin Variables Study Program

Fifteen batches of 15.2 cm (6.0 inches) wide prepreg tape described in the 5th Quarterly Report were received from Hexcel. Ten batches varied resin stoichiometry three batches varied processing, and two batches utilized Anchamine DL and Tonox 22 substituted for Jeffamine AP-22. Table 4 describes the specific resin stoichiometry and processing variable evaluated. The standard LARC-160 batch processed under identical laboratory conditions to the resin variable prepreg batches has been received but physical or mechanical properties have not been determined at this time.

Prepreg material physical properties specified on the purchase order to Hexcel were as follows:

Resin solids: 35-41 (%)

Volatiles: 9-15 (%)

Fiber Areal Weight: 131-137 grams/m^2

Table 5 presents detailed prepreg physical properties reported by Hexcel and Rockwell. Although apparent fiber collimation and distributional control was improved over previous 15.2 cm (6.0 inches) wide tape, resin solids and fiber areal weight varied across the tape width in excess of target requirements.

Composite Physical Properties

Laminate panels 15.2c15.2-cm (6x6 inches), 14 ply were fabricated to the standard two stage imidizing and cure process and postcured as specified in the 5th Quarterly Report and Appendix A.

NDC C-scan tests resulted in 100% transmission through all resin stoichiometry and processing variable panels except EX207, resin run number 5. Panel EX207 had a 10% excess concentration of Jeffamine AP22 and showed 40% transmission. The two panels with amine components, Anchamine DL and Tonox 22, showed 70% and 0% transmission respectively. NDI C-scan recordings are shown in Figures 13 through 27.

Target fiber volume of 60 $\pm$ 2% was achieved in five of fifteen panels fabricated. Low and high fiber volumes in the remaining panels is attributed to prepreg resin content inconsistencies within each laboratory scale tape roll. Detailed composite physical properties are presented in Table 6.

Composite Mechanical Properties

Flexural and short beam shear (SBS) properties were determined on each postcured panel at room temperature and 316C (600F). High flexural strength and modulus and SBS strength was achieved in all specimens tested with the exception of panel EX219 which employed the Tonox 22. Detailed properties are presented in Table 6.

Composite TMA-Tg Properties

Figure 28 shows a plot of Tg temperatures determined for laminates as a function of Jeffamine AP-22 concentration. The NE and BTDE quantities were held constant at the standard formulation concentrations. Although the number of data points is limited, and only one determination per laminate sample was made, the plot indicates that Tg increases with increasing AP-22 concentration up to +10 percent. Data were too limited with respect to variable NE/BTDE concentrations to determine a trend in Tg temperature variations.

Significantly, panel EX 219 (Tonox 22) yielded a higher Tg than all other laminates. Individual TMA-Tg curves are presented in Figures 29 through 32.

3.2 TASK (b) - PROCESS DEVELOPMENT

Analysis of bleeder material absorbtive limits has continued during this report period. Data are generated from each laminate fabricated. It is anticipated that these data can be developed into a nomographic presentation or a formula relating prepreg resin content, laminate thickness, and bleeder fabrics to an ultimate cured laminate fiber volume of 60 $\pm$ 2%.

3.3 TASK (c) - FABRICATION AND TEST

3.3.1 Fabrication - Mechanical Properties Specimens

Initial laminate panels to be used for mechanical properties testing were laid up and autoclave cured using the single stage insitu imidizing and cure process described in the 2nd Quarterly Report. These panels were used to obtain all postcured condition mechanical properties specified in the test matrix, Table 7. Resin flow control proved to be a problem using this cure cycle, sometimes resulting in high composite fiber volumes in the range of 64 to 68%. All laminates for specimen fabrication had essentially zero void content as determined analytically, and by NDI C-scan test (refer to the 3rd Quarterly Report).

Process optimization studies performed in Task (b) (refer to the 3rd, 4th, and 5th Quarterly reports) led to a two stage processing requiring an imidzing cycle where volatiles are removed to $<$ 2% from the stacked prepreg prior to the autoclave cure. Resin flow control is maintained during imidization by low vacuum levels and a Celgard 4500 or 4510 (1) microporous polypropylene film which allows volatile matter to escape through a perforated tooling plate while the membrane contains the low viscosity resin. Excess resin is absorbed into bleeder materials calculated to yield a laminate with a target 60 $\pm$ 2% fiber volume.

(1) Celgard is a product of the Celanese Plastics Co., Morris Court Summit, N.J. 07901

The autoclave cure is accomplished between two flat tooling plates. Since the major portion of volatile matter is removed in the imidizing cycle, the laminate can be treated similarly to epoxy materials. Final laminate cure can be accomplished in the temperature range of 287 to 326C (550 to 625F) for time periods of 3 to 2 hours. Shorter cure cycles will be investigated under Task (b).

This two stage process was employed in the fabrication of all laminate for mechanical properties specimens that were aged for 125 hours at 316C (600F). All panels had essentially zero void with fiber volumes in the 61 to 63 percent range. NDI C-scan recordings confirmed high quality and are shown in Figure 33 through 38. The detailed description of this two stage processing is given in Appendix A.

3.3.2 <u>Testing - Mechanical Properties</u>

Testing was performed in accordance with the matrix, Table 7. Three specimens for each test mode and temperature were tested in the postcured and aged 125 hours, 316C (600F) conditions.

3.3.2.1 Beam Test Description

Tension and compression critical beams were employed to determine $(0)_t$ tension (F_{tu}, E_t, ε_{ult}, $\mu\%$) and $(0)_t$ and $(0, \pm 45, 90)_s$ compression (F_{cu}, E_c, ε_{ult}, $\mu\%$) properties. The beam design is described in the 4th Quarterly Report.

Analytical studies performed by Mr. Mark Shuart, NASA-LaRC, proved that the 352 Kg/m^3 (22 pcf) honeycomb core signifcantly affects the measured strength and elastic modulus properties of composite specimens[1]. A computer program was developed by NASA-LaRC to assess the actual effect this core has on the laminate properties and to establish property adjustment factors. Bulk core properties for both aluminum, 352 Kg/m^3 (22 pcf), and 301 CRES, 639 Kg/m^3 (40 pcf), core materials were developed by Rockwell International and transmitted to NASA-LaRC for use in the computer program in developing the composite property adjustment factors. These data were reported in the 4th Quarterly Report. Specific adjustment factors are given in the individual mechanical property data Tables 8 through 13.

During test, individual specimens were stabilized at each test temperature for $10 \,^{+1}_{-0}$ minutes prior to application of stress at a load rate of 1.27 mm (0.05 inch)/ minute. Data were obtained by autographic recording of axial strain gages installed on the composite specimens at the beam midpoint.

3.3.2.2 Tensile Test Description

Tensile coupons were employed to determine $(0)_t$, $(90)_t$, $(\pm 45)_s$ and $(0, \pm 45)_s$ and $(0, \pm 45, 90)_s$ tension properties. Specific properties determined were F_{tu}, E_t, ε_{ult}, $\mu(\%)$ and ν. The $(0)_t$, $(90)_t$ and $(\pm 45)_s$ coupons employed a straight sided design and the $(0, \pm 45, 90)_s$ coupons were necked down in the test section. Specimen design descriptions are given in the 3rd Quarterly Report.

During test, specimens were loaded at 1.27 mm (0.05) inch/minute after stabilizing for $10 \,^{+1}_{-0}$ minutes at temperature. Data were obtained using biaxial strain gages mounted back-to-back on two of three specimens in each test group.

Load/strain data were obtained incrementally in testing postcured condition specimens by digital readout using a data logger. Stress/strain data plots were made using a Hewlett Packard 9820 computer system. The remaining single specimen in each group was instrumented with clip-on hand down extensometers.

(1) "An Evaluation of the Sandwich Beam in Four Point Bending as a Compressive Test Method for Composites" NASA Technical memorandum 78783, Mark J. Shuart, Carl A. Herakovich, September 1978.

In testing the 125 hour 600F aged coupon specimens, load/strain data was obtained autographically from biaxial strain gages at a constant load rate of 1.27 mm (0.05 inch)/minute.

3.3.2.3 Compression Test Description

Compression coupons were employed to determine $(90)_t$ and $(\pm 45)_s$ compression properties, F_{cu}, E_c and ε_{ult}, μ (%). The compression specimen is a 7.62 cm long x 2.54 cm wide (3.000 X 1.000 inch) coupon. Specific tolerances and test fixture design are described in the 3rd Quarterly Report. During test, specimens were loaded, after stabilizing at each test temperature for 10 $^{+10}_{-0}$ minutes, at a constant load ratio of 1.27 mm (0.05 inch)/minute. Load/strain data were obtained autographically using a hang down deflectometer.

3.3.2.4 Flexural and Short Beam Shear Test Description

Specimens were machined from 0^o, 26 ply, nominal 0.063 mm (2.5 mils)/ply, 1.65 mm (0.0565 inch) thick test panels. Specimen configurations are in accordance with ASTM D790 (flexural) and ASTM D2344 (short beam shear). Respective span to thickness ratios for each test are 32:1 and 4:1. Strain measurements were made autographically during each test using an isolated deflectometer positioned at the specimen midpoint. Elastic modulus properties were derived from load/strain curves obtained in the flexural tests and the load/strain curves obtained in the SBS tests were used to give a positive indication of when actual specimen failure occurred. Specimens were loaded at 1.27 mm (0.05 inch)/minute after being stabilized at the test temperature for 10 $^{+10}_{-0}$ minutes.

3.3.3 <u>Test Results - Mechanical Properties</u>

3.3.3.1 Tension

Data obtained during testing are summarized in Table 14. The effects of test temperature and postcuring versus aging (125 hour, 316C (600F) conditioning) on composite mechanical properties are presented graphically in Figure 39.

Testing problems were experienced in some cases with beam specimens at 204C and 316C (400F and 600F) when either composite facing-to-core or steel facing-to-core bond failures occurred. Test data were tabulated at the composite stress level reached when bond failure occurred and are therefore not averaged. To resolve the bond failure problem, HT424 epoxy/phenolic adhesive, 439 grams/m^2 (0.10 psf), and FM 34B-18, 659 grams (0.135 psf), adhesive will be substituted for the presently employed FM 400 and 439 grams/m^2 (0.09 psf) FM 34B-18 adhesives.

Tension test results, adjusted per paragraph 3.1.2.1 of $(0)_t$ beam specimens show that the postcured specimens have higher strength than the aged under all conditions except room temperature. All tensile strengths were quite high starting at 2068 MN/m^2 (300 ksi) at -132C (-290F) and steadily decreasing to 1648 MN/m^2 (239 ksi) at 316C (600F). The $(0, \pm 45, 90)_s$ and $(\pm 45)_s$ tensile coupons in the postcured condition also maintained higher strength than the aged counterparts although the spread was very close. There was virtually no decrease in the postcured $(0, \pm 45, 90)_s$ tensile strength between -132C(-270F) and 316C (600F). The resin critical $(90)_t$ aged tensile coupon specimens showed good strength retention in comparison with the postcured units, having slightly higher 132C (-270F) and room temperature strengths and slightly lower 204C (400F) and 316C (600F) strengths.

Elastic modulus properties of the fiber critical $(0)_t$ specimens were not significantly affected regardless of test temperature while the $(0, \pm 45, 90)_s$, 316C (600F) test specimens showed some modulus loss. For the resin critical $(\pm 45)_s$ and $(90)_t$ coupons, a gradual decrease in elastic modulus properties was noted between -132C(-270F) and 316C (600F).

Detailed tensile properties and failure modes from beam tests are presented in Tables 8 and 9 and properties from coupon testing are presented in Tables 15 through 22. Stress/strain curves from beam and coupon testing are presented in Appendix B.

3.3.3.2 Compression

Data obtained during test are summarized in Table 23. Effects of test temperature and postcuring versus aging (125 hours, 316C (600F) conditioning) on composite mechanical properties are presented graphically in Figure 40.

Testing problems occurred in compression test of 204C (400F), $(0, \pm 45, 90)_s$ beams as discussed in the tensile results section, paragraph 3.3.3.1. The same resolution to the problem will be employed in future tests.

Analysis of compression test results indicated somewhat different trends in strength properties than found in tension, with lower ultimate strengths in the fiber critical orientations, $(0)_t$ and $(0, \pm 45, 90)_s$, and higher strengths in the resin critical orientations, $(90)_t$ and $(\pm 45)_s$. For the $(0)_t$ beam tests the aged, room temperature strength was higher than the postcured specimens as found in tension tests. A greater loss from room temperature compression strength was noted at 316C (600F) than in the tension tests, a 37% reduction for postcured and 50% reduction for aged condition. Beam specimens with $(0, \pm 45, 90)_s$ fiber orientation, postcured condition, showed only 33% strength loss from room temperature to 316C (600F) while the aged specimens had a 20% loss indicating a postcure effect. The resin dependent $(90)_t$ and $(\pm 45)_s$ coupon specimen strengths were almost identical in both postcured and aged conditions at each test temperature except for the postcured 316C (600F) tested $(\pm 45)_s$ specimens, indicating the influence of the resin. Strengths losses from room temperature to 316C (600F) ranged from 65% in the postcured $(\pm 45)_s$ specimens, while the aged specimens lost only 20%, again indicating a postcure effect on the resin.

Elastic modulus properties of the $(\pm 45)_s$ specimens at each test temperature were increased after aging at 316C (600F), while the $(90)_t$ specimens showed no significant difference. $(0)_t$ and $(0, \pm 45, 90)_s$ specimens showed no significant change in elastic modulus properties, regardless of test temperature or aged condition.

Detailed compression data and failure modes from beam tests are presented in Tables 10 through 13. Table 24 presents the data for coupon testing. Stress/strain curves are presented in Appendix B.

3.3.3.3 Flexural

Results of flexural strength tests on postcured and aged specimens show a drop in strength from room temperature to 316C (600F) of 51% and 34% respectively. Specimens tested at -132C (-270F) yielded respective strength increases from room temperature of 18% and 6.2%. The aged specimens demonstrated higher strengths at all test temperatures except -132C (-270F). Elastic modulus properties were not significantly affected regardless of aged condition or test temperature. Failure modes of -132C (-270F) and room temperature tested specimens were by outer fiber tension and by

compression in specimens tested at 204C (400F) and 316C (600F). Detailed data are presented in Table 25 and the relative performance of postcured and aged specimens is shown graphically in Figure 41.

3.3.4 Short Beam Shear

Results of short beam shear tests on postcured and aged specimens show exceptionally good strength retention at all test temperatures. The strengths of postcured speccimens was slightly higher at -132C (-270F) and room temperature than the aged specimens, equivalent at 204C (400F) and slightly lower at 316C (600F). All failure modes were by interlaminar shear. The relative performance of postcured and aged specimens is presented graphically in Figure 42 and tabulated data in Table 26.

3.3.4 Fabrication - Structural Elements

3.3.4.1 Hat-Stringer Stiffened Skin Elements

The hat-stringer stiffened skin design is presented in the 2nd Quarterly Report. Skin and stringer fabrication procedures described in the 3rd Quarterly Report were employed except as noted herein. The finalized detailed process is described in Appendix A.

Difficulties were encountered during fabrication of some later 193 cm (76 inches) long hat elements in the form of (± 45) layers locally wrinkling along the upper cap corners. Wrinkling was caused by insufficient compaction of the 30.5 X 193 cm (12.0 X 76.0 inches) 16 plies thick unidirectional cap perform during the imidizing cycle. However, NDI C-scan test results showed that essentially void free parts were attained.

The wrinkling problem was resolved by modifying the unidirectional cap imidizing procedure by applying 84KN/m^2 (25 inches of Hg) vacuum plus 172KN/m^2 (25 psi) autoclave pressure at the end of the 114C (240F) cycle. Resultant preforms were reduced in bulk thickness from 3.30 to 3.56 mm (0.13 to 0.14 inch) to 2.79 to 2.41 mm (0.11 to 0.095 inch) which decreased material movement during final compaction in the cure process. The Celgard contained the resin during pressurization and no excessive losses were noted. Additional debulking of the lay up was accomplished after final lay up using a molded SMC 250 silicone (1) rubber caul at room temperature under 689 KN/M^2 (100 psi). The resultant preform on the aluminum mandrel closely matched the shape of the rubber caul, producing smooth, wrinkle free surfaces. Hat elements were autoclave molded using the in situ cure process originally described in the 2nd Quarterly Report and updated in Appendix A. Excellent NDI-C scan test results were obtained on all hats in the cured and postcured conditions, as typically shown in Figure 43.

Concave warpage of the hat stringers occurs along the element flange and inside cap length with a maximum flatness deviation of approximately 5.08 mm (0.20 inch) at the midpoint as shown in the photograph, Figure 44. This condition was partially removed after bonding the three hat elements (EX191, EX193, EX195) to skin (EX197) and was almost completely removed when the 193 cm (76 inches) long skin/stringer assembly was cut into five 30.48 cm (12 inches) long test sections, Specimen No's EX195-1, -2, -3, -4, -5. This lengthwise concave warped conditions is caused by imbalance in the hat design, where the major quantity of fiber contained in the cap section places the part's neutral axis off center. This condition would pose a problem in test of the stringer stiffened skin elements that are to be delivered

(1) SMC250 rubber is a product of "D" Aircraft Products, Anaheim, Ca.

to NASA-LaRC in Task (e) of the program, since nonuniform cap-skin loading would result from the concave condition.

To resolve this problem, the 127 cm (50 inches) long hat mandrel tool was modified by reverse rolling it concave to the cap surface, 6.35 mm (0.25 inch) at the mid-point. This modification, 1.27 mm (0.05 inch) more than actually observed in the elements as they are removed from the tool, was made on the assumption that upon removal from the reverse cured tool after curing, the hat element would approach a flat condition. Any minor longitudinal warping, concave or convex, would be eliminated when the hat is bonded to the skin.

This approach was verified in molding hat elements EX249 and EX250 to be used in fabricating hat-stiffened skin/stringer elements in Task (e). These parts were fabricated, per specific procedures defined in Appendix A, on the reverse formed tooling. Resultant hat elements were flat and linear with no warpage. The photograph in Figure 45 shows the flatness of the hat element.

Due to the hat tooling mass, heat rise rates during the insitu imidzing cure cycle are extremely low. For example in the final critical temperature range between 257 to 271C (500 to 525F) the average heat rise rate is only 0.51 to 0.55C (0.92 to 1.0F)/minute. Figure 46 gives actual heat rise rate ranges observed during two hat element autoclave curing cycles. This indicates that the LARC-160 system is apparently not affected by long dwell periods close to the hot melt resin flow point, demonstrating that a large processing window exists. Heating rate comparisons are plotted in Figure 46 for typical flat panels, which show 340 minutes total cure time versus 590 minutes for hat elements, not counting cool-down.

The vacuum bag oven cure employing the pressure augmentation process described in the 3rd Quarterly was used to bond the three heat elements to skin using FM34B-18, 439 grams/m^2 (0.09 psf), adhesive. Tooling was improved for fabrication of the subsequent 193 cm (76 inches) long article, EX195, by employing inverted "T"-bars to distribute bonding pressure to hat flange/bond areas. This innovation improved handling and assembly of tooling elements. The tooling concept is shown in photographs, Figures 47 through 51. A section of the NDI C-scan recording of the hat-to-skin bond is shown in Figure 52.

3.3.4.2 "I"-Stringer Stiffened Skin Element

Aluminum tooling, utilizing the same design principles employed for the steel tooling described in the 2nd and 3rd Quarterly Reports, was employed in the "I"-stringer element fabrication. The tooling was increased in length from 96.5 cm (38.0 inches) to 127 cm (50 inches). The shift from mild steel to 6061-T6 aluminum alloy was made due to slow, nonuniform heat rise rates experienced in early curing studies with steel.

A design change in the "I"-stringer 0°, 14 ply, 2.03 mm (0.08 inch) cap was made to eliminate the concave condition transverse to the cap length found in early fabrication studies (reference 3rd Quarterly Report). Rather than placing all 14 0° plies on the outside of the cap, these were split. seven plies each side of the ($\pm$ 45) web-cap layers. This resulted in nearly perfect flat and straight caps. The detailed fabrication process is described in Appendix A.

NDE C-scan tests showed considerable void areas in the caps. To determine the void characteristics, 120X photomicrographs, were taken of discreet cap areas where both 100% and 0% sound penetrations were recorded. From these it was determined that the void shapes were irregular micron sized pits distributed throughout the cap thickness. The cap side showing 100% sound penetration showed no voids in the photomicrographs. Actual respective void volumes determined analytically were 8.31% and 1.13% and fiber volumes 58-62%. NDI C-scans and photomicrographs of the "I"-stringer cap are shown in Figure 53.

"I"-stringers were bonded to the skin assembly with FM34B-18-104 carrier adhesive film using the vacuum bag pressure augmentation process in an autoclave described in the 4th Quarterly Report.

Since the maximum pressure augmentation area-to-bond area available in this part design is only 1.5:1, an autoclave was required in the bonding operation. A minimum 3:1 pressure augmentation area to bond area is required for one atmosphere oven bonding operations. The bonding sequence is shown in Figures 54 through 58.

3.3.4.3 Honeycomb Sandwich Panel Element

Fabrication of sandwich panel EX150, 63.5x71.1x4.85-cm (25.0x28.0x1.91-inches) was accomplished in accordance with processes described in the 5th Quarterly Report. The skins were comprised of unbalanced (0_2, $\pm$ 45, 0), 5 ply, nominal 0.144 mm (5.7 mil)/ply unidirectional tape. In the 5th Quarterly Report, these skins were erroneously specified as $(0, \pm 45, 90)_t$, 4 ply. NDI C-scan recordings indicated a good skin to core bond was attained.

Celion 1K, 34x35, 5 harness satin weave graphite fabric/LARC-160, 20 ply doubler stock was fabricated using the two stage processing, immidization and autoclave curing. Panel size was 30.5x60.9x0.33-cm (12x24x0.130-inches). NDI C-scan showed 100% transmission; a recording is shown in Figure 59. Doubler stock was machined to a tapered configuration and bonded to the ends of each sandwich element with FM34B-18 adhesive film.

3.3.5 Preparation and Testing - Structural Elements

All structural elements, subsequent to the hat-and "I"-stiffened skin/stringers panels reported in the 4th Quarterly Report, were tested at the North American Aircraft Division (Los Angeles) in a 1957KN (440,000 lbs.) capacity Tinius Olsen universal testing machine. Test preparation and testing was accomplished as follows:

(1) Specimen ends were ground flat and parallel to within $\pm$ 0.127 mm ($\pm$ 0.005 inch).

(2) One half of all structural elements were aged 125 hours at 316C (600F). Initial weights, and percent weight loss after aging are shown in Table 27.

(3) Hat-and "I"-stiffened skin/stringer panels were stabilized at each end by potting in place to approximately 1.27 cm (0.50 inch) thick to match equivalent thickness precision ground tool steel load plates. Potting materials were selected based on test temperature and processed as shown in Table 28.

(4) Sandwich panel ends were stabilized by the tapered doublers described in paragraph 3.3.4.3. Doublers were clamped between parallel bars resting on the test bed during test to prevent specimen ends from spreading.

(5) Bi-axial gages were positioned and bonded at the midpoint of the center stringer cap and skin, in a back-to-back pattern and in rosette, 0^o, 45^o, 90^o on one web the center stringer. Sandwich panels were instrumented with back-to-back strain gages in rosette, 0^o, 45^o, 90^o at the midpoint.

(6) Hat-and "I"-stiffened skin/stringer panel edges were clamped to provide fixity; sandwich panel edges were not clamped.

(7) Specimens were positioned in the test machine on a special spherical seat fixture designed to ensure optimum axial alignment. A pre-load of 2244 to 8896 N (500 to 2000 lbs) was applied and the specimen was aligned by adjusting the spherical seat to match back-to-back skin and hat cap axial strain gage deflections to a tolerance of 50μ. Typical specimens are shown in position on the test machine in Figures 60 through 63.

(8) After stabilizing at test temperature, a compressive load was applied incrementally up to the individual specimen calculated design ultimate. Strain measurements were taken at each loading increment. Specific target ultimate loads are shown in Table 29.

3.3.6 Test Results - Structural Elements

Hat - and "I" - stringer stiffened skin panel testing was completed at -132C, R.T. and 316C (-270F, R.T. and 600F). Two sandwich panels were tested; one at R.T. and one at 316C (600F). Data are summarized in Table 30 and load/strain curves are presented in Figures 64 through 79. Figures 80 through 90 show failure modes of elements that failed during test.

All of the room temperature elements met the design ultimate load requirement of 525KN/m (3000 lbs/in.). Specimen EX109/EX110A hat stringer failed while being held at the predicted ultimate load, showing good correlation between theory and design practice. A small degree of strength degradation was noted in the hat stiffened skin/stringer element EX109/EX110B during -132C (-270F) testing where failure occurred at 117 KN (26,250 lbs.), 3.4% below room temperature design ultimate. This specimen had previously been tested to design ultimate of 120.8 KN (27,150 lbs) at room temperature and then fatigue tested to 265 kilohertz, 5% to 67% of design ultimate (compression/compression). Premature failure may have been caused by the combination of previous static and fatigue testing and resin embrittlement at -132C (-270F).

The strain gage data showed, for the most part, linear compression properties for the section designs tested. This was most apparent in the tests on the two honeycomb panels, which represent a balanced section and the six "I"-stringer panels which are unbalanced. The unbalanced hat-stiffened skin/stringer elements showed fairly linear strain increase until just before failure where it was found that probable local instabilities caused fairly large excursions in the gage readings in some test cases. This nonlinearity would be aggrevated if the section designs were more unbalanced.

In terms of structural efficiency, the hat-stiffened panel yielded the lightest weight design. It should also be noted that the $(0, \pm 45, 90)_s$ skin configuration of the hat-and "I"-stiffened panels was dictated as a design requirement, and thus these sections did not represent optimal designs. A measure of the structural efficiency of these configurations may be obtained by plotting the design parameters as shown in Figure 91. The relative weights per unit area of the three configurations are as follows:

Hat-stiffened panel:	4.5Kgm/m^2 (0.939 lbs/ft^2)
"I"-stiffened panel:	5.1Kgm/m^2 (1.04 lbs/ft^2)
Honeycomb panel:	5.6Kgm/m^2 (1.14 lbs/ft^2)

3.4 TASK (d) - LAMINATE FABRICATION

The required laminates for this task have been submitted to LaRC. These laminates, identified as CL6C-11, CL12C-6, and CL24C-7, were fabricated using Hexcel Batch 23091, 5 mil, 30.5cm (12 inch) wide prepreg tape. The cosmetic quality of the prepreg was excellent. Laminates were laid-up, $(0, \pm 45)_s$ fiber orientation, 63.5x127-cm (25x50-inches) by 6, 12, and 24 plies to obtain the required thicknesses of 0.75, 1.5, and 3.0mm (0.030, 0.060, and 0.120 inch). Two stage processing, imidization and cure, was accomplished as defined in Appendix A.

After post curing for 4 hours at 316C (600F), the laminate panels were C-scanned and trimmed to finished dimensions, 60x120-cm (24x48 inches). C-scans are shown in Figures 92, 93, and 94. Laminate physical properties are presented in Table 31.

3.5 TASK (e) - SKIN/STRINGER PANEL FABRICATION

The scope of Task (e) was amended by contract change to eliminate all skin/stringer panels except the three secondarily bonded hat-stiffened demonstration components, 23x120-cm (9x48-inches). This was done in order to accelerate generation of Task (c) mechanical properties data to meet material selection requirements for the SCR (Supersonic Cruise Research) program.

Deletion of the cocured and mechanically fastened skin/stringer configurations was justified on the basis of manufacturing producibility and loss of weight savings advantage,respectively. The requirement for small panels, 23x30-cm (9x12 inches), was deleted since equivalent specimens having secondarily bonded "I"-and hat-stringers were being fabricated and tested under Task (c). Selection of the hat-stringer, rather than the "I" configuration, was made on the basis of test data which showed that both met load requirements,with the hat configuration having a weight savings advantage.

Hexcel Batch 23328, 5.7 mil, 30.5-cm (12 inch) wide prepreg tape was used in fabricating $(0, \pm 45, 90)_s$ fiber orientation 8 ply skins for this task. While the appearance of this prepreg was comparable to Batch 23091 used for Tasks (d) and (f), no laminate met C-scan requirements. Four attempts were made to fabricate laminate skins for this task: CL8C-10, 76x127-cm (30x50-inches); EX228, 30.5x 127-cm (12x50-inches); CL8C-13, 61x127-cm (24x50 inches); and EX227, 61x127-cm (24x50-inches). Laminate CL8C-13 was blistered and was not C-scanned. C-scans for CL8C-10, EX227 and EX228 are shown in Figures 95, 96 and 97. As of this report, no specific cause has been established to explain the poor laminate quality. It is thought that the problem was with the prepreg tape, however, since the cure processing used produced excellent quality laminates for Tasks (d) and (f).

An additional 11.3Kg (25 lbs) of 5.7 mil prepreg tape, Batch 23451, was produced by Hexcel. The physical appearance of this tape was equal to the previous two batches, 23091 and 23328. Two 8 ply skin laminates (CL8C-14 and CL8C-18), both 61x127-cm (24x50 inches), have been made from this material. C-scans of both laminates, presented in Figures 98 and 99 show excellent quality. In addition, 2 ply ($\pm$45) layups for the hat-section webs and two 5 ply (0, $\pm$ 45, 0_2) layups 63x91-cm (25x36-inches) for Task (c) sandwich skins were made from this material.

Unfortunately, during post cure of laminate CL8C-14, the oven malfunctioned resulting in an over run of the 316C (600F) temperature destroying the laminate.

Since Batch 23451 was completely used for the layups previously described, an immediate order was placed with Hexcel for an additional 11.3Kg (25 lbs) of 5.7 mil prepreg tape. This material was received March 12. Qualification laminates and an 8 ply skin laminate for this task are in process.

3.6 TASK (f) - HONEYCOMB PANEL FABRICATION

Six honeycomb sandwich panels 25.4x25.4-cm (10x10-inches) required by this task have been fabricated and delivered to LaRC. These panels consisted of 0.15-cm (0.060 inch) thick, $(0,90)_t$ face sheets bonded to HRH327-.48cm - 1.81Kg (-3/16-4.0) by 2.54-cm (1 inch) thick honeycomb cure. The face sheets were bonded to BR34 primed core with FM34 adhesive, 0.44 Kg/m^2 (0.09 psf). Face sheet-to-core bonding was accomplished using the cure cycle defined in the 5th Quarterly Report.

Two 12-ply laminates, designated as CL12C-8 and CL12C-9, 61x91-cm (24x36 inches) were laid up using Hexcel Batch 23091, 5 mil prepreg tape. The layup was such that the $(0,90)_t$ fiber orientation was symmetrical about the neutral axis of the honeycomb core. Laminate cure was as defined in Appendix A. Post cure of the laminates was accomplished in two stages: 2 hours at 316C(600F) free standing and 2 hours at 316C(600F) in the bonded condition which also postcured the adhesive bond line. Physical properties of the post cured laminates are shown in Table 31. Specimens for physical properties determination were taken from laminate trim areas and received the full 4 hour exposure.

C-scans of laminates CL12C-8 and CL12C-9, showing the location of the three face sheets 28x56-cm (11x22-inches) cut from each, are presented in Figures 100 and 101. Face sheet pairs 8C9C, 8A8B, and 9A9B were bonded to honeycomb core. C-scans of the three sandwich panels, identified as 8A, 9A, and 9C, and showing the location of each 25.4x25.4-cm (10x10-inches) panel, designated #1 through #6, are shown in Figures 102, 103 and 104.

3.7 TASK (g) - CHOPPED FIBER MOLDING FABRICATION

Development of fabrication processes for Celion/LARC-160 chopped fiber molding has been held in abeyance pending completion of Tasks (c), (d), (e) and (f).

4.0 WORK PLANNED FOR NEXT REPORT PERIOD

4.1 TASK (a) - QUALITY ASSURANCE

Analysis of remaining neat resin and prepreg batches from the Variables Study and regular production will be completed. Particular attention will be given prepreg batch 23238 from neat resin batch 23245, Cut 5, for which processing difficulties were encountered.

Results of the Resin Variables Study will be evaluated to establish production limits of LARC-160. Three 10-pound batches of prepreg, using resin formulated within these limits, will be obtained from Hexcel for determination of repeatability and storage/out-time limitations. The proposed test requirements for this study are shown in Table 32.

4.2 TASK (b) - PROCESS DEVELOPMENT

Analysis of bleeder material abosrbitive limits will be completed. Data will be used to establish relationships of prepreg resin content and laminate thickness to bleeder fabric types in order to realize a cured laminate fiber volume of 60±2%.

Processing parameters will be developed for chopped fiber molding.

Studies will be performed to simplify and improve reliability of the imidization and cure cycles. Target improvements are as follows:

(1) Reduce the number of steps in the imidizing cycle.
(2) Increase the prepreg preform imidizing temperature and/or time at temperature, thereby increasing the LARC 160 resin viscosity when hot melt occurs during the cycle. This will allow application of 1378 KN/m^2 (200 psi) pressure at the initiation of the cure cycle. This in turn will eliminate the chance of error when pressure is applied in the temperature range of 274C to 287C (525 to 550F) with the existing cure cycle.
(3) Eliminate the intermediate 163C (325F) step in the cure cycle by raising the temperature from RT to ultimate cure temperature within the established heat rise rate band.

4.3 TAKS (c) - SPECIMEN FABRICATION AND TEST

Testing of honeycomb sandwich panel elements, in the postcured and aged condition, will be completed.

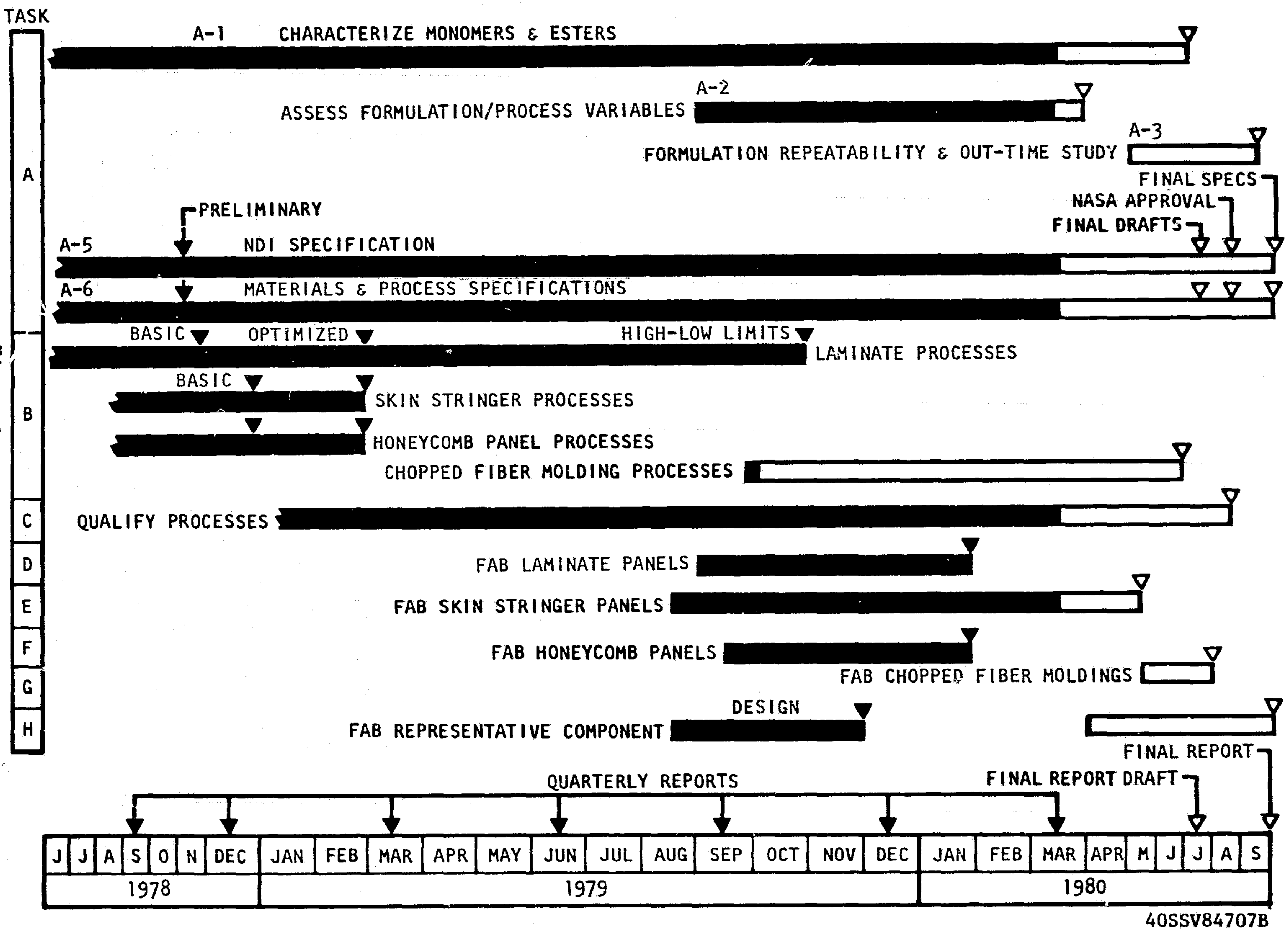
4.4 TASK (e) - SKIN STRINGER PANEL

Fabrication of three demonstration skin stringer panels, with bonded hat-stiffeners, will be completed. The panels will be NDI C-scanned and sent to LaRC.

4.5 TAKS (g) - CHOPPED FIBER MOLDING

Fabricating of chopped fiber moldings will start on completion of process development, Task (b).

DEVELOPMENT OF CELION/LARC-160 STRUCTURAL ELEMENTS - NAS1-15371
PROGRAM SCHEDULE



Space Transportation System
Development & Production Division
Space Systems Group

Rockwell International

Figure 1

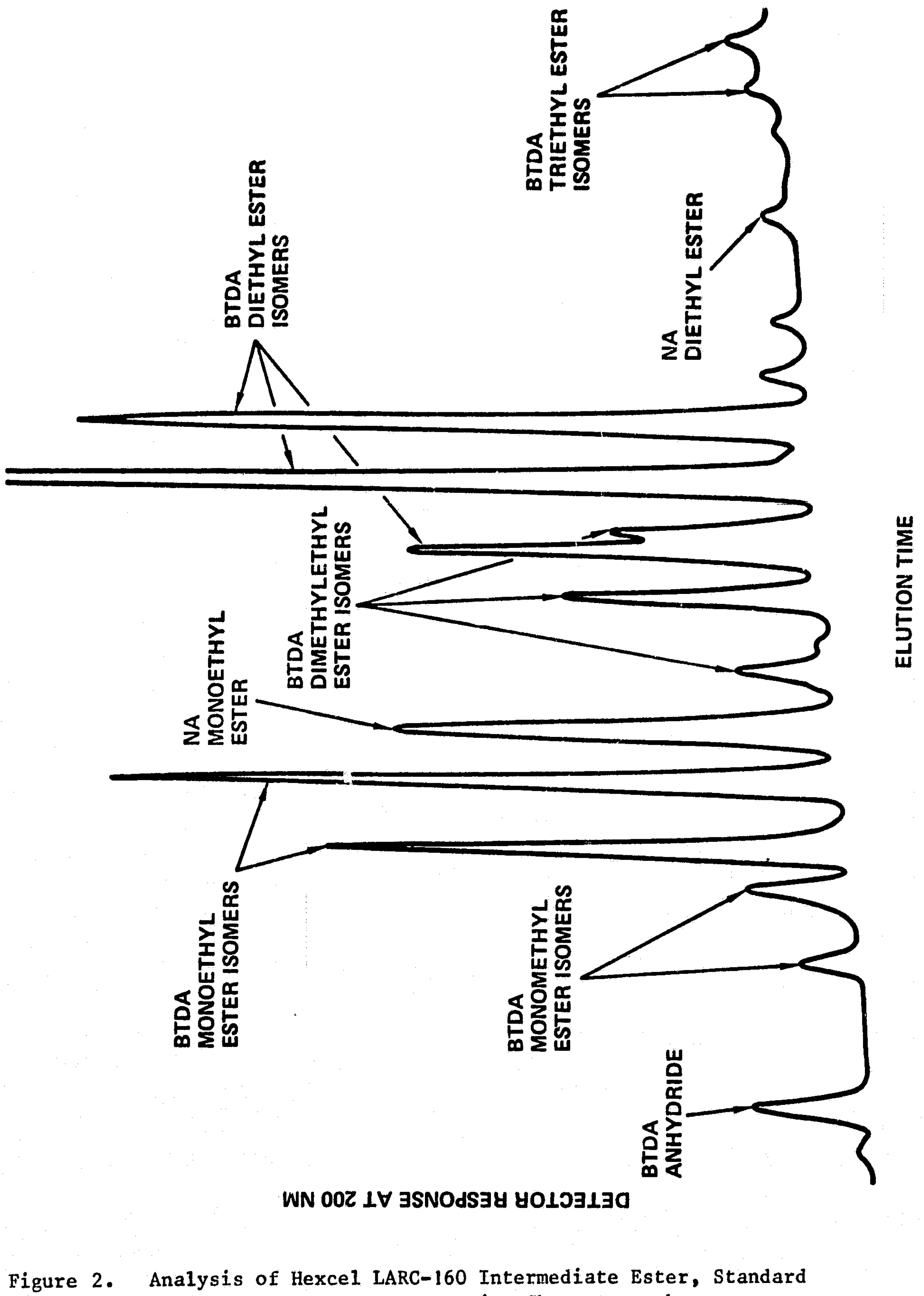


Figure 2. Analysis of Hexcel LARC-160 Intermediate Ester, Standard Batch 22746, by Ion-Suppression Chromatography

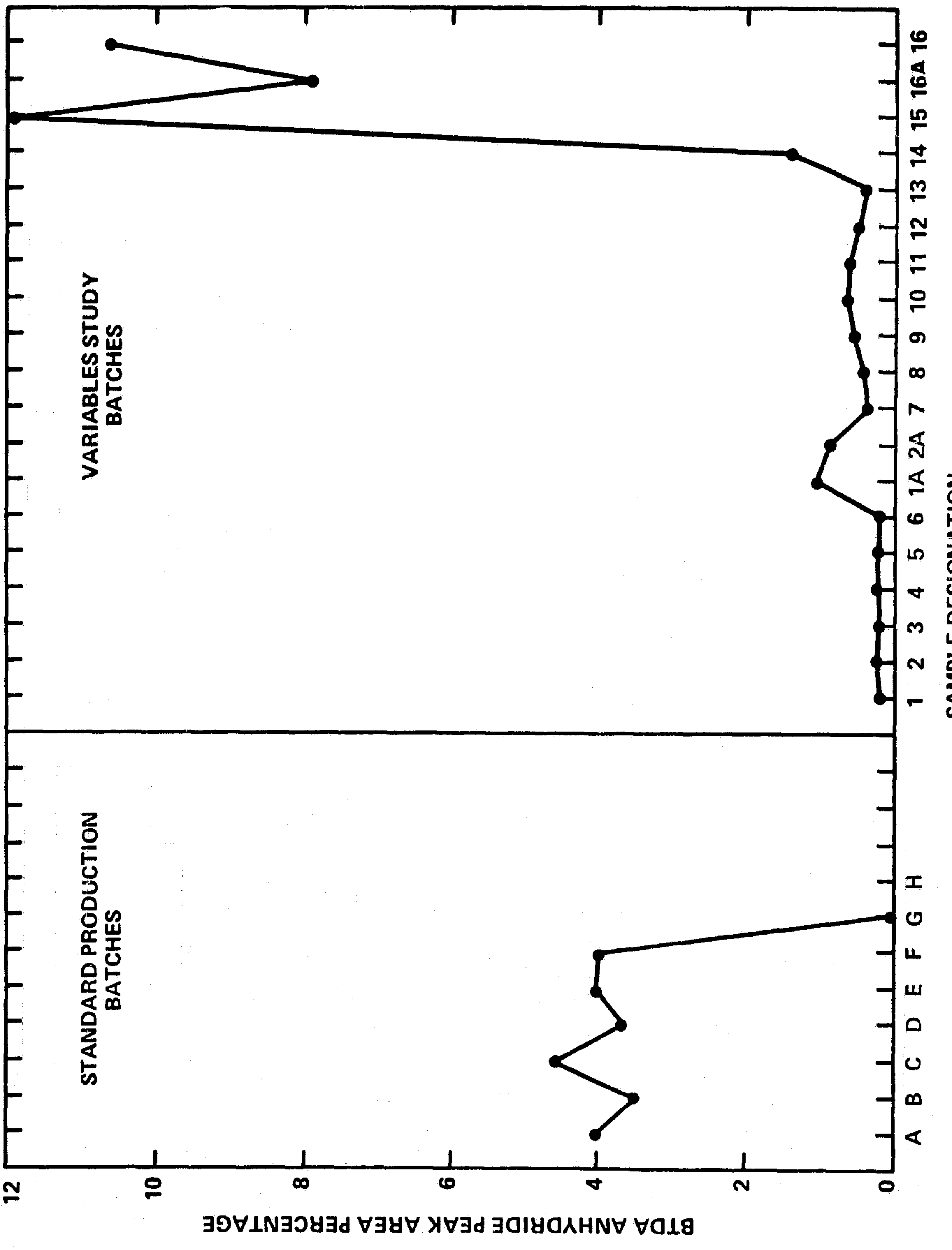


Figure 3. Relative BTDA Anhydride Content in Hexcel LARC-160 Batches by Ion-Suppression Chromatography

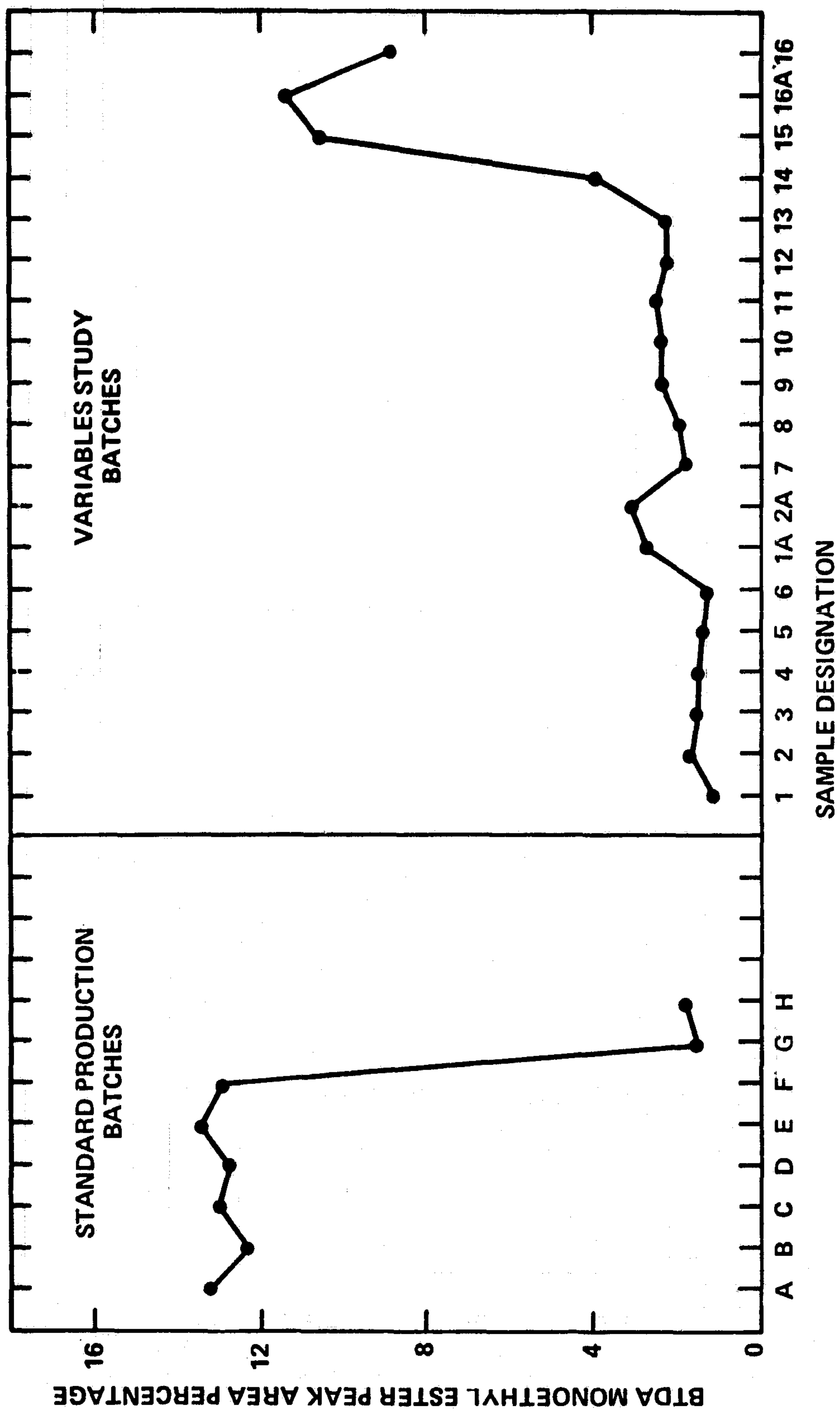


Figure 4. Relative BTDA Monoethyl Ester Content in Hexcel LARC-160 Batches by Ion-Suppression Chromatography

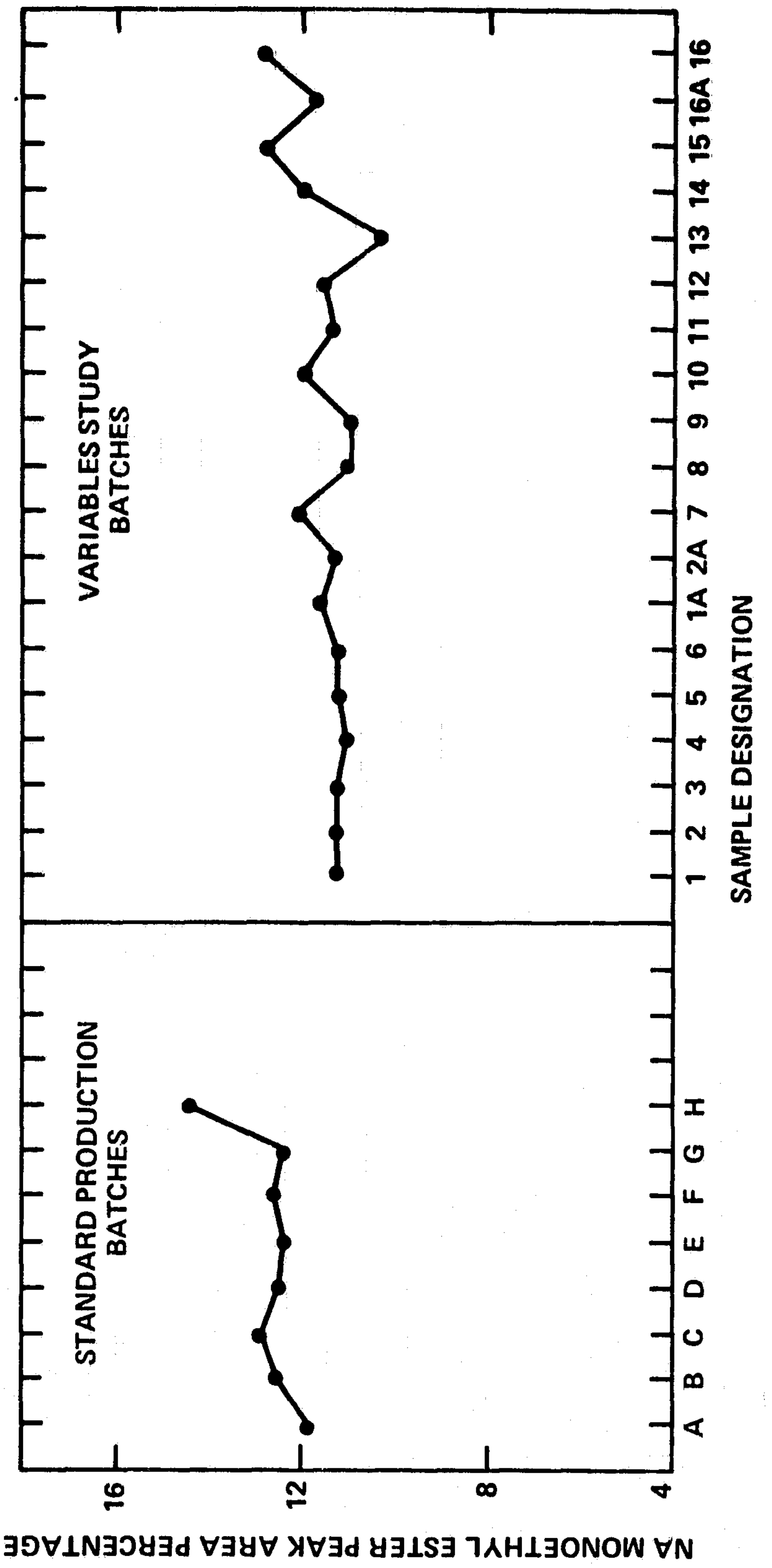


Figure 5. Relative NA Monoethyl Ester Content in Hexcel LARC-160 Batches by Ion-Suppression Chromatography

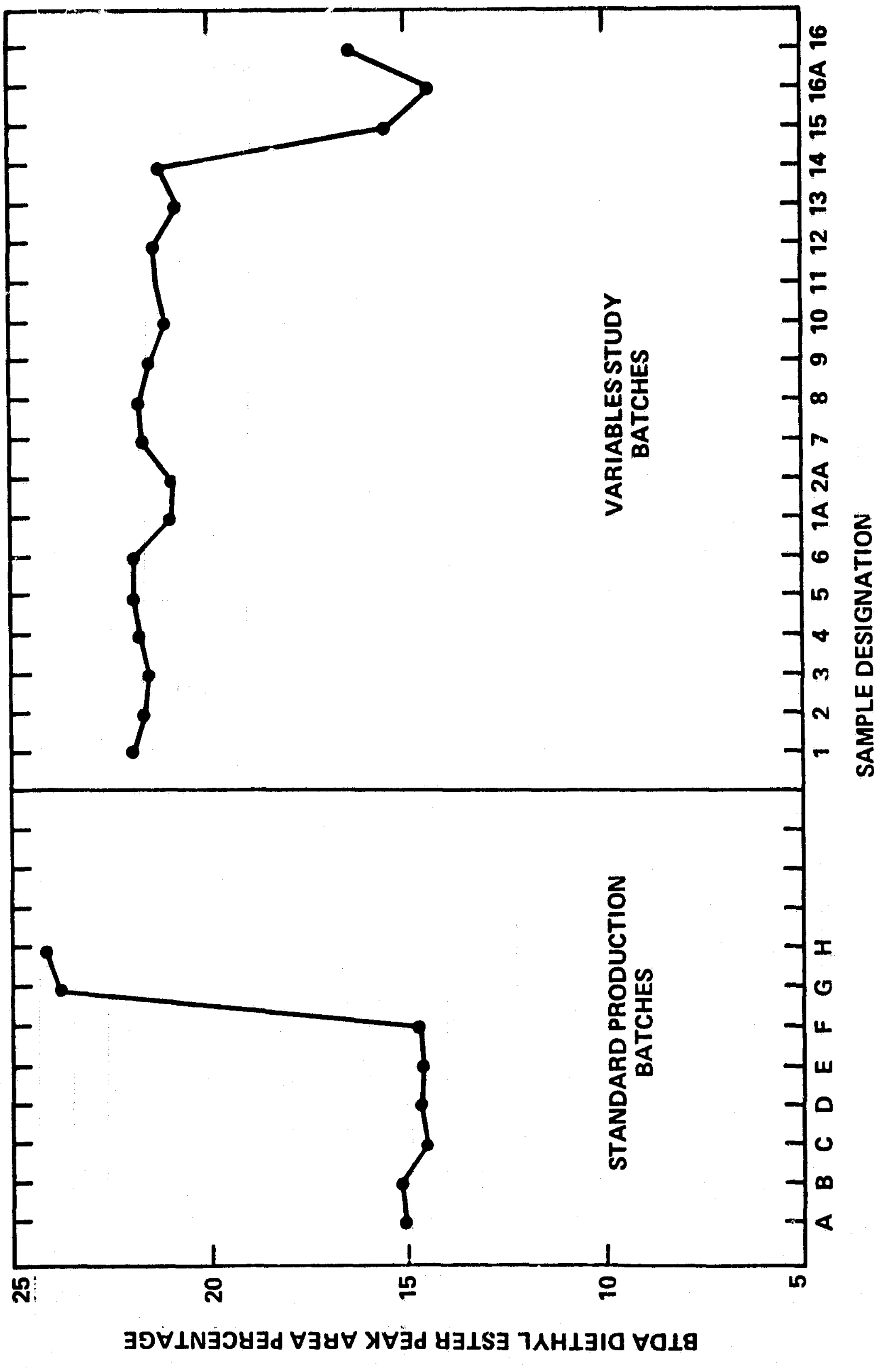


Figure 6. Relative BTDA Diethyl Ester Isomer 3 Content in Hexcel LARC-160 Batches by Ion-Suppression Chromatography

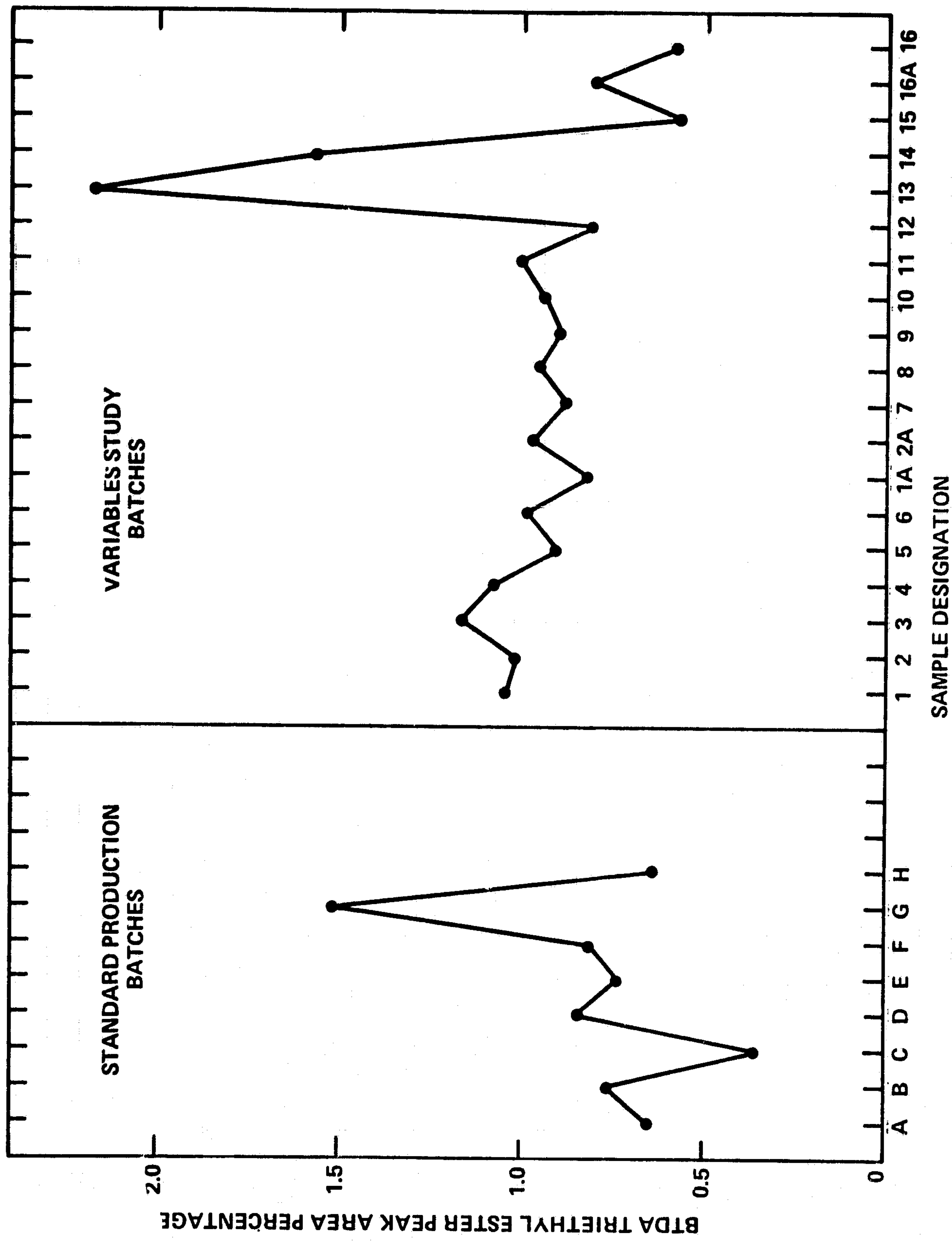


Figure 7. Relative BTDA Triethyl Ester Content in Hexcel LARC-160 Batches by Ion-Suppression Chromatography

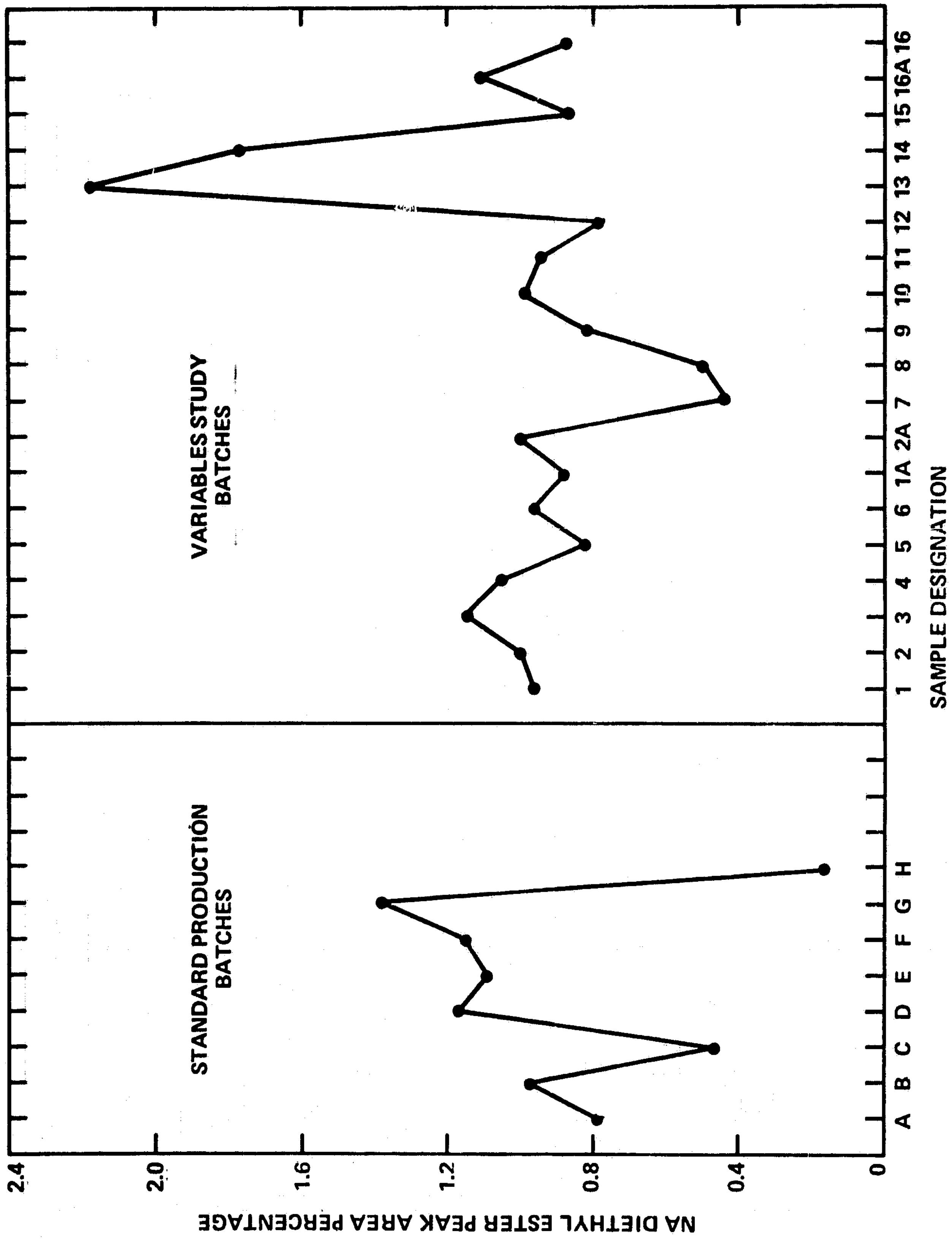
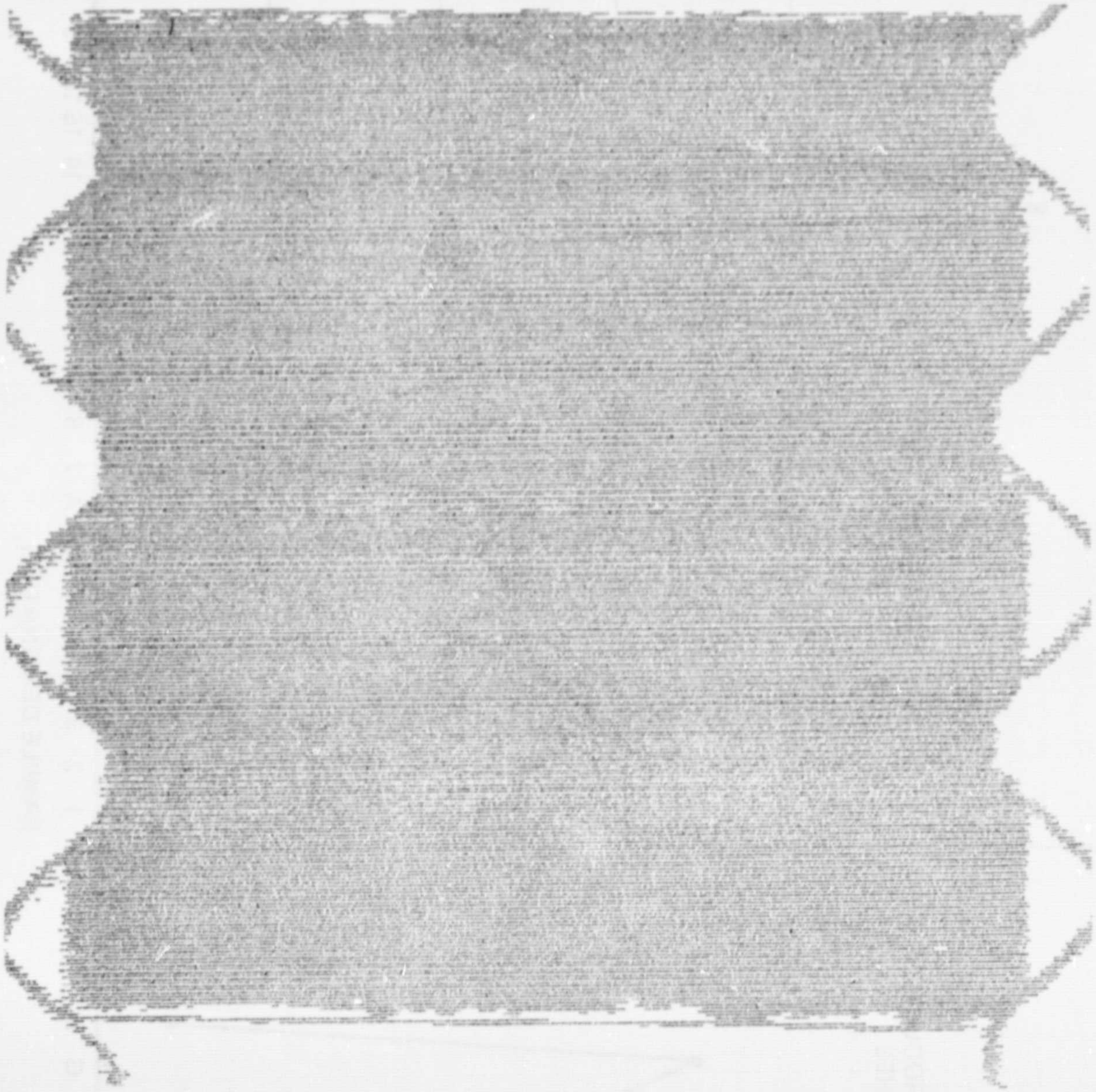
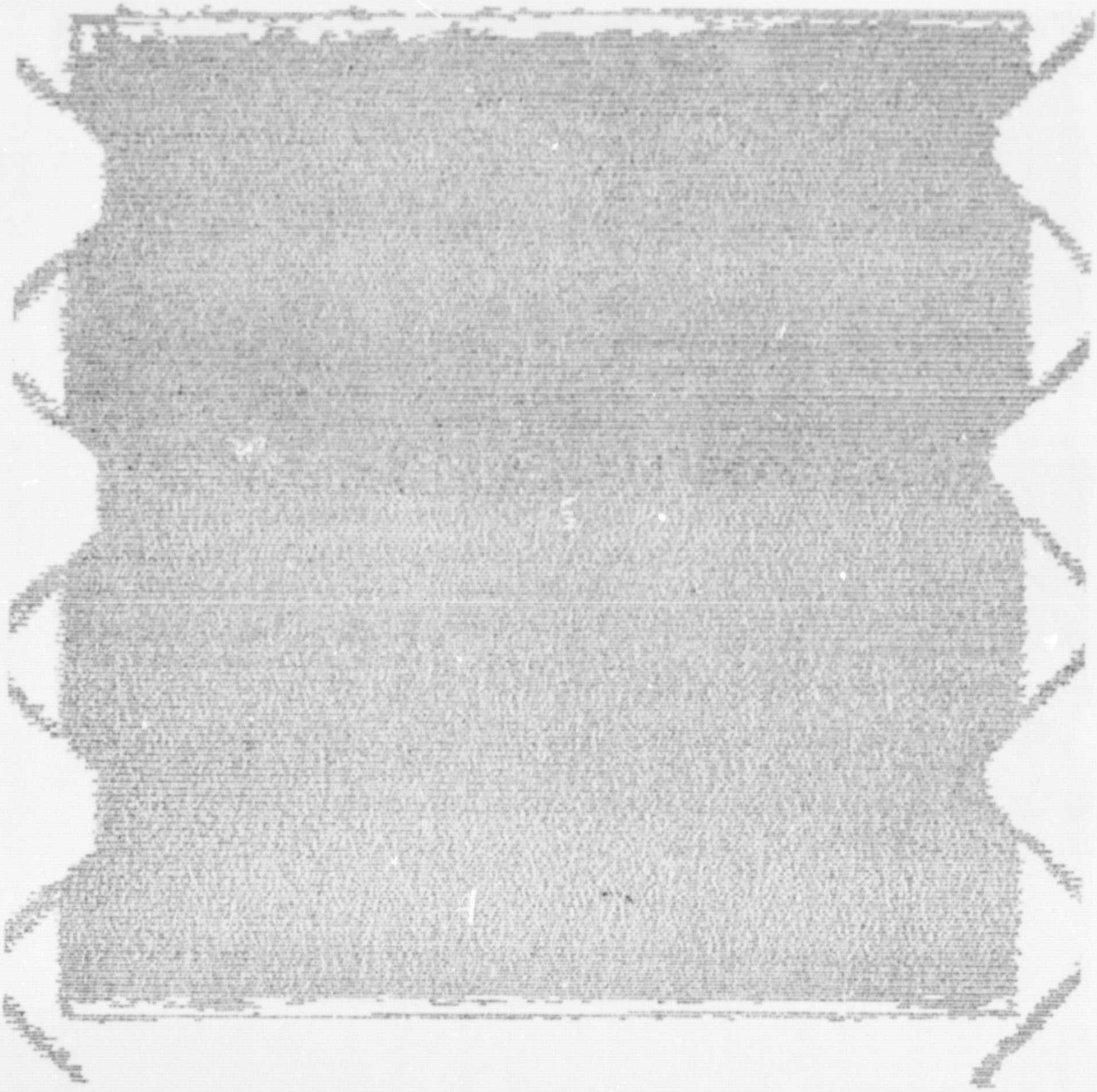


Figure 8. Relative NA Diethyl Ester Content in Hexcel LARC-160 Batches by Ion-Suppression Chromatography



COMPOSITE DESCRIPTION: EX223
PREPREG MFG/BATCH: HEXCEL/23328R3
NO. OF PLIES/ORIENTATION: 14 PLIES $(0)_T$
THICKNESS MM (MILS): 1.52-1.63 (60-64)
PANEL SIZE CM (INCH): 15.2 X 15.2 (6 X 6)
PROCESS VARIABLE: STANDARD 2 STAGE PROCESS

Figure 9. C-Scan of Quality Assurance Panel EX223.



COMPOSITE DESCRIPTION: EX224

PREPREG MFG/BATCH: HEXCEL/23328R3

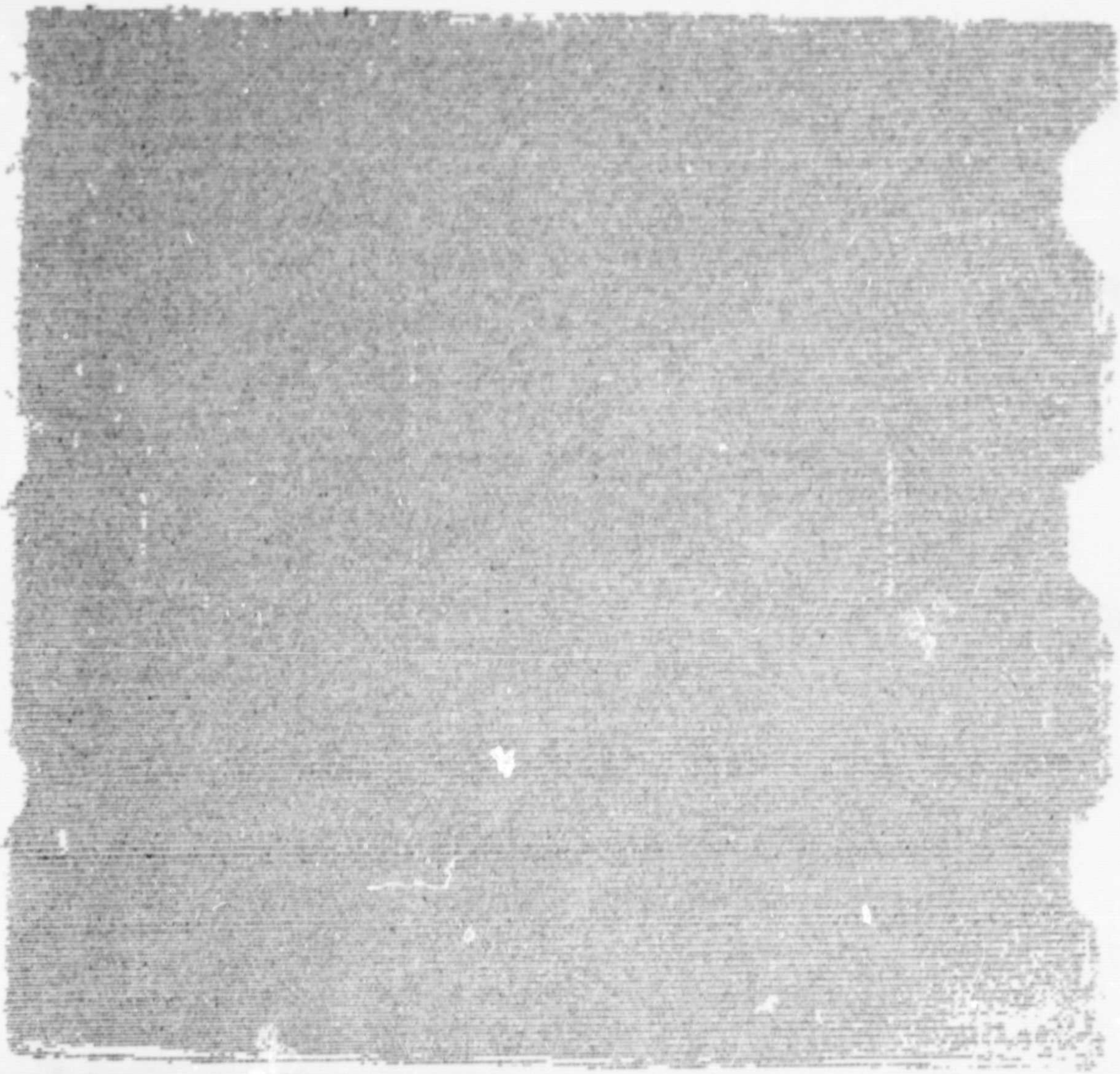
NO. OF PLIES/ORIENTATION: 11 $(0)_T$

THICKNESS MM (MILS): 1.27-1.35 (50-53)

PANEL SIZE CM (INCH): 15.2 X 15.2 (6 X 6)

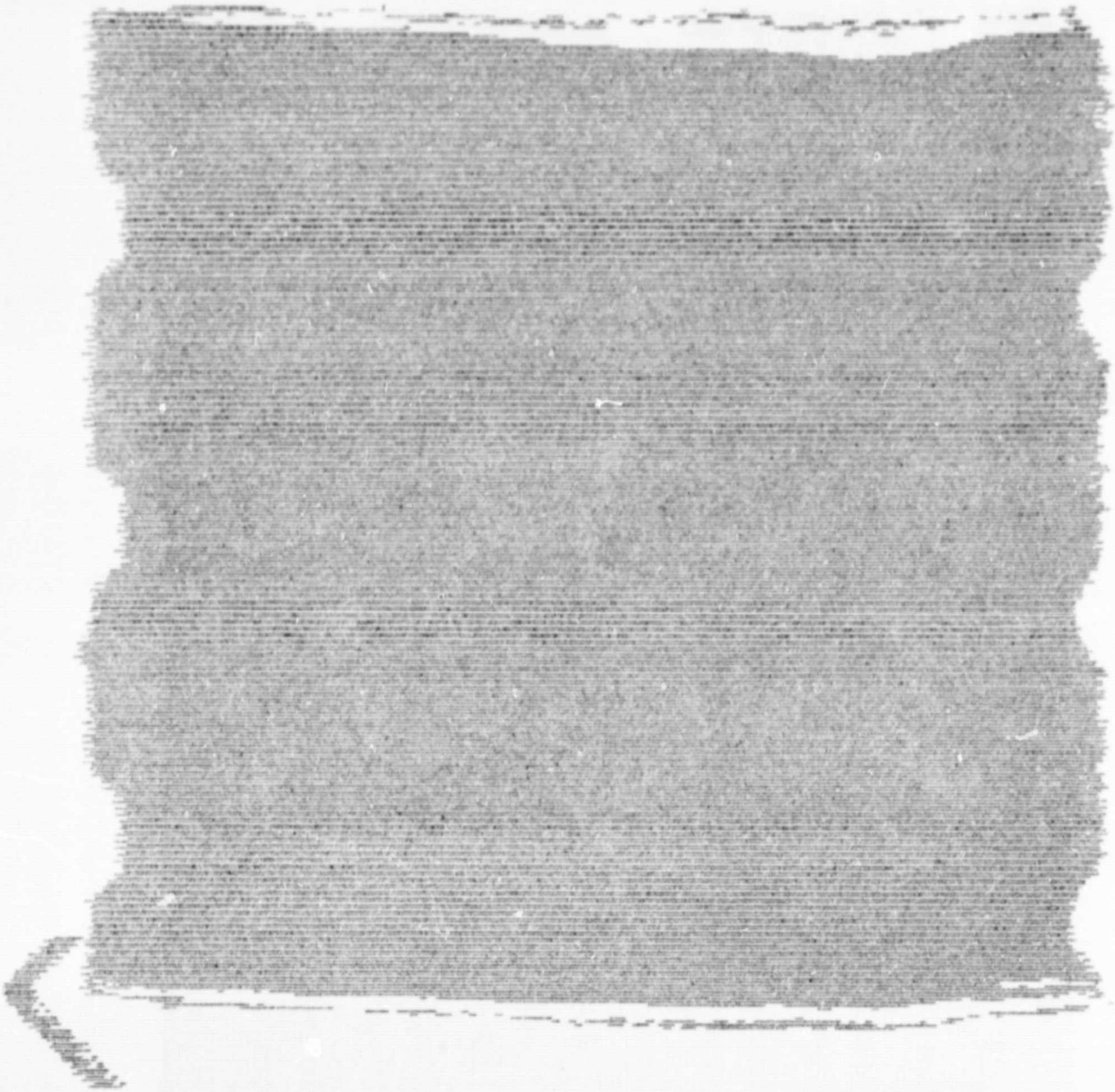
PROCESS VARIABLE: STANDARD 2 STAGE

Figure 10. C-Scan of Quality Assurance Panel EX224.



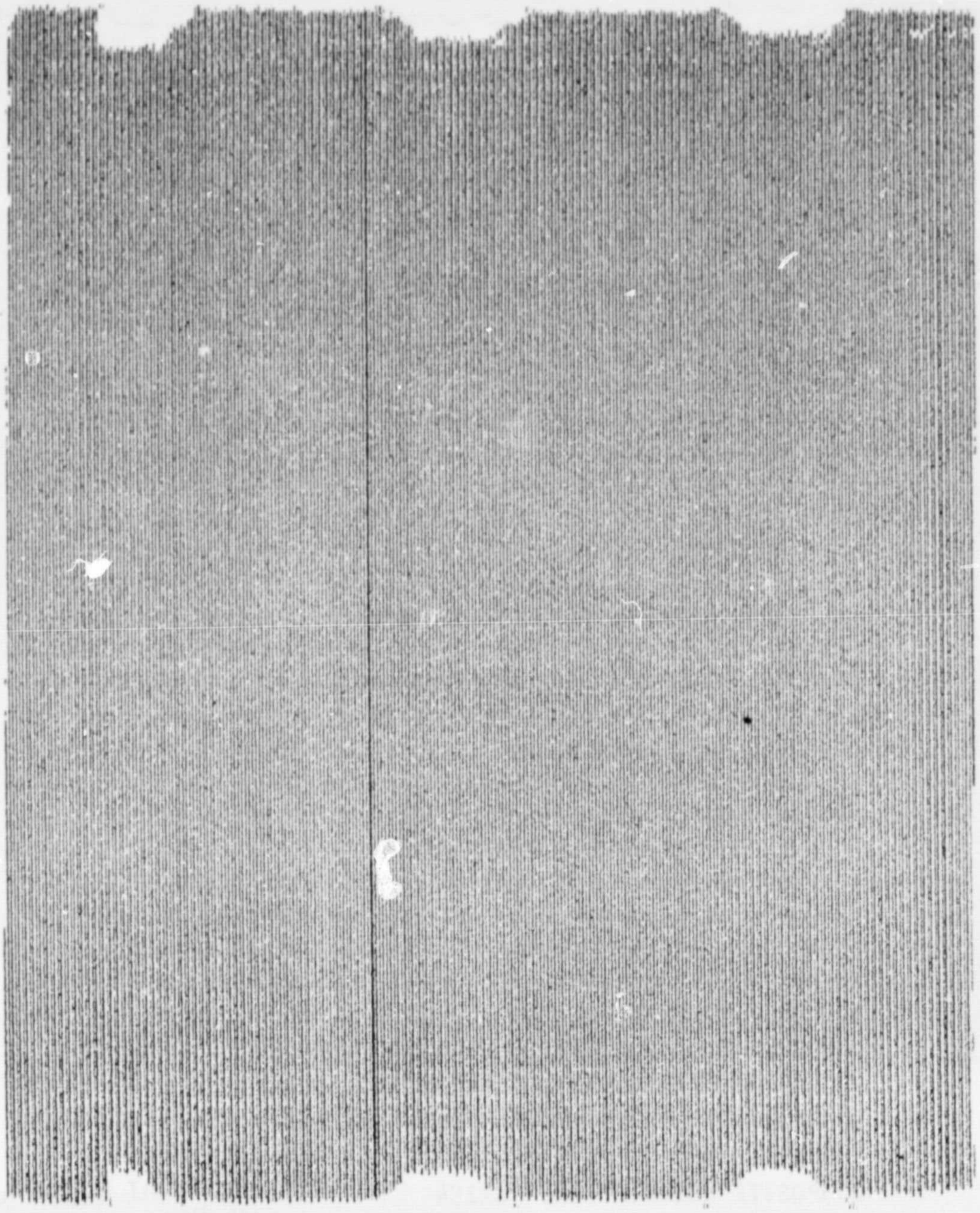
COMPOSITE DESCRIPTION: EX237
PREPREG MFG/BATCH: HEXCEL/23451
NO. OF PLIES/ORIENTATION: 11 $(0)_T$
THICKNESS MM (MILS): 1.40-1.52 (55-60)
PANEL SIZE CM (INCH): 15.2 X 15.2 (6 X 6)
PROCESS VARIABLE: STANDARD 2 STAGE PROCESS

Figure 11. C-Scan of Quality Assurance Panel EX237.



COMPOSITE DESCRIPTION: EX254
PREPREG MFG/BATCH: HEXCEL/23451
NO. OF PLIES/ORIENTATION: 11 $(0)_T$
THICKNESS MM (MILS): 1.27-1.52 (50-60)
PANEL SIZE CM (INCH): 15.2 X 15.2 (6 X 6)
PROCESS VARIABLE: STANDARD 2 STAGE PROCESS

Figure 12. C-Scan of Quality Assurance Panel EX254



PANEL EX217	FORMULATION VARIABLES		PROCESS VARIABLES	
PREPREG RUN & (BATCH)	CONC. AP-22	CONC. ANHYDRIDES	COOK TIME	REFLUX TIME
1 (22990)	+2%	STD	STD	STD

Figure 13. C-Scan Resin Variable No. 1

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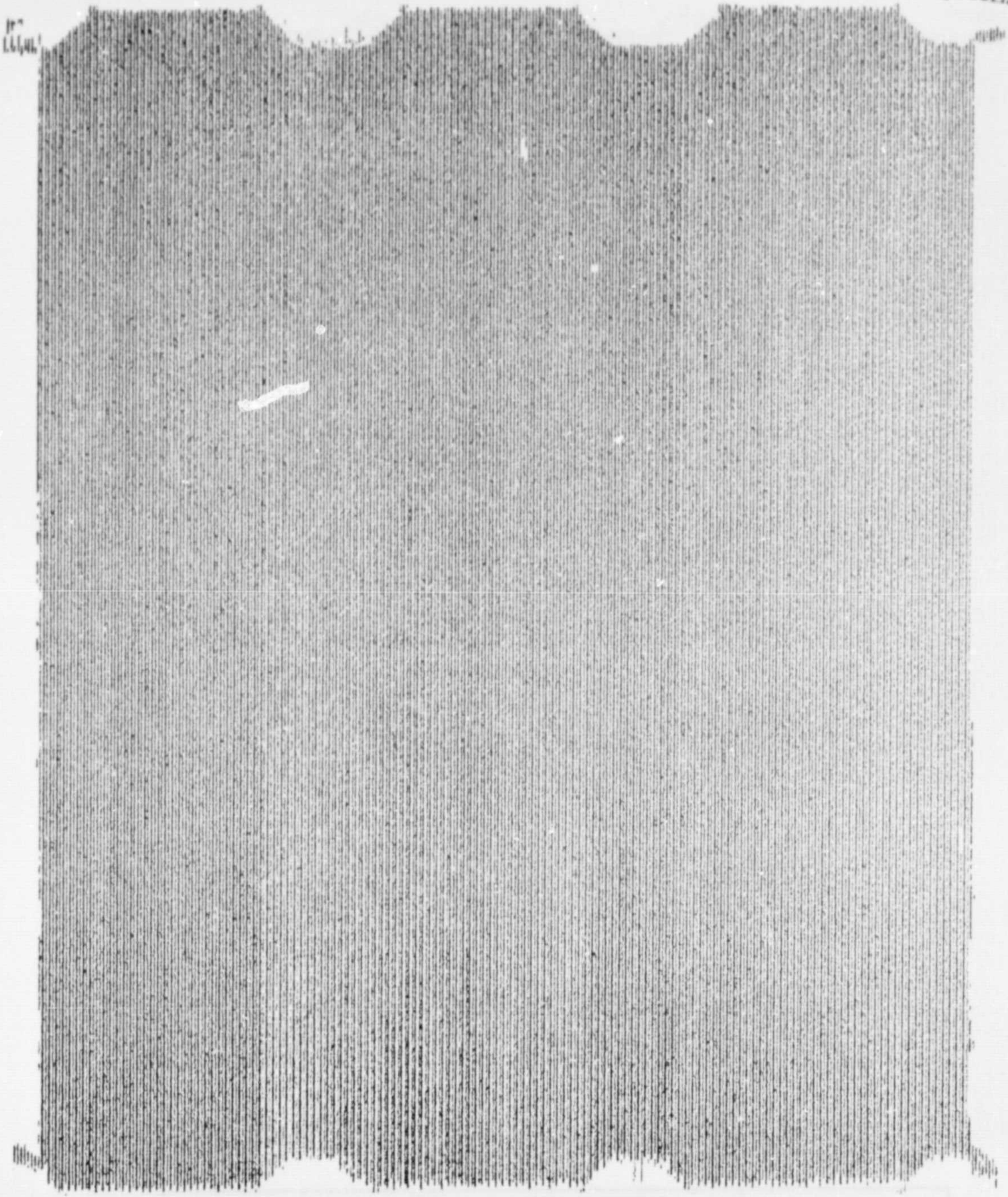
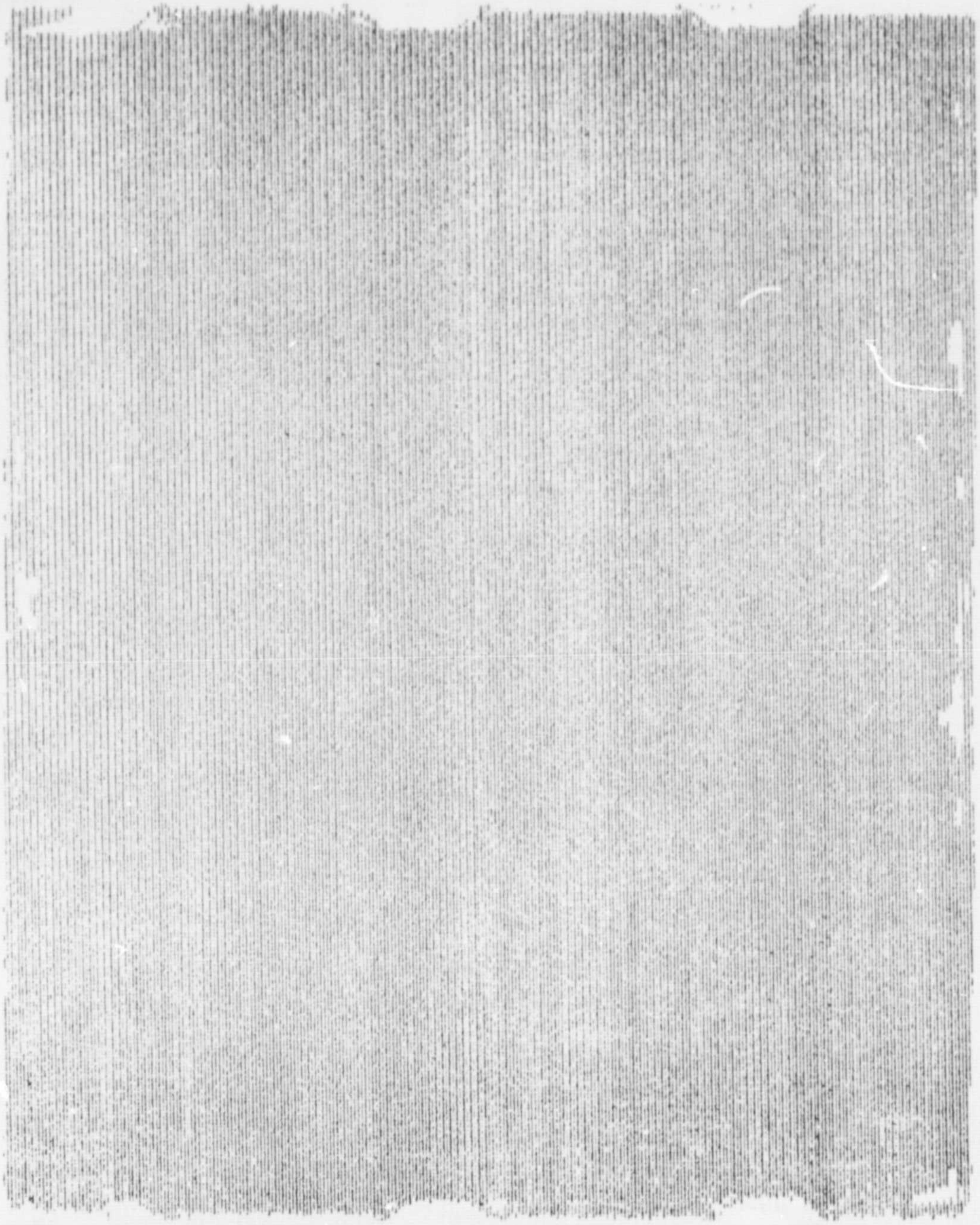


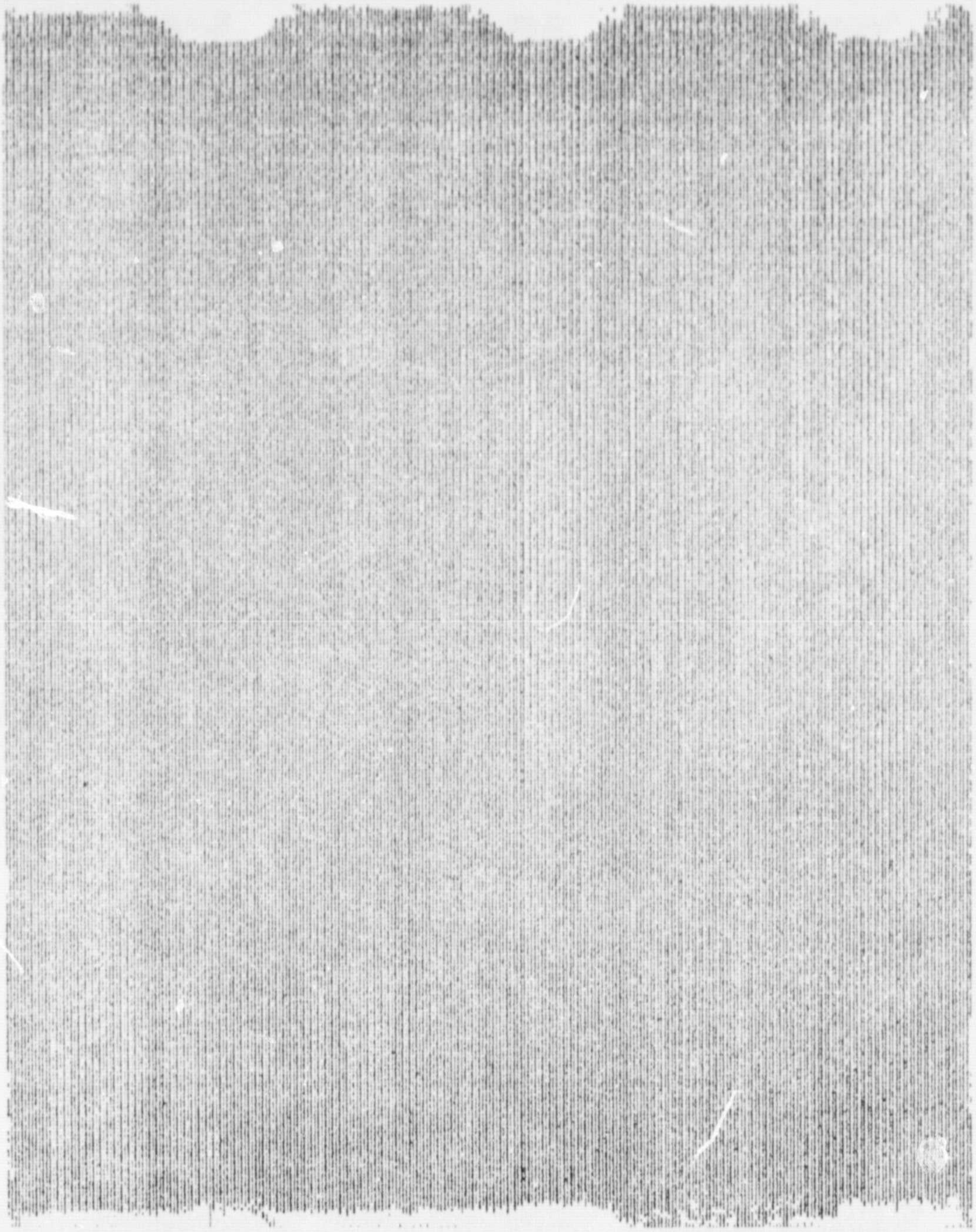
PANEL EX218	FORMULATION VARIABLES		PROCESS VARIABLES	
PREPREG RUN & (BATCH)	CONC. AP-22	CONC. ANHYDRIDES	COOK TIME	REFLUX TIME
2 (22991)	-2%	STD	STD	STD

Figure 14. C-Scan Resin Variable No. 2



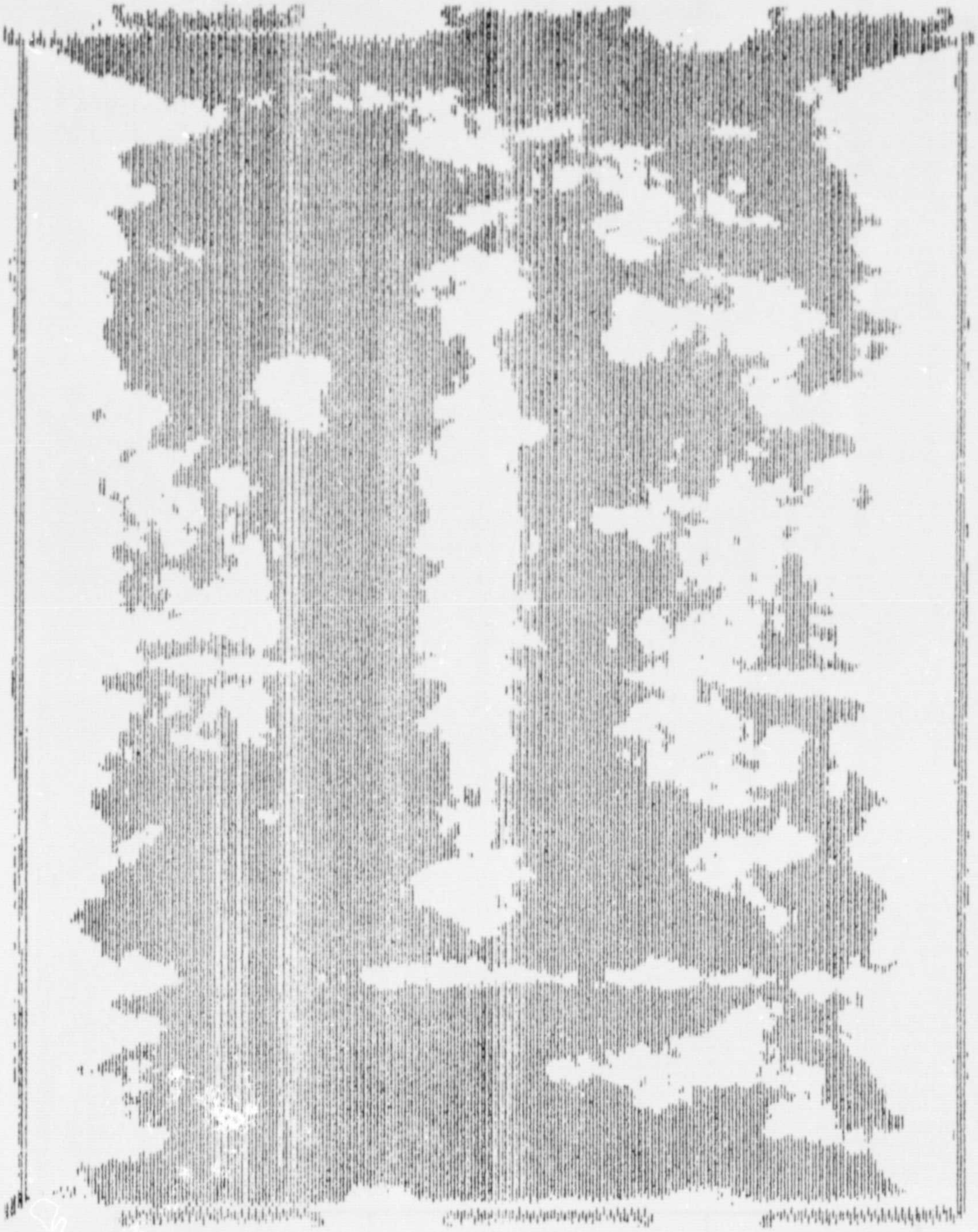
PANEL EX205	FORMULATION VARIABLES		PROCESS VARIABLES	
PREPREG RUN & (BATCH)	CONC. AP-22	CONC. ANHYDRIDES	COOK TIME	REFLUX TIME
3 (22945)	+5%	STD	STD	STD

Figure 15. C-Scan Resin Variable No. 3



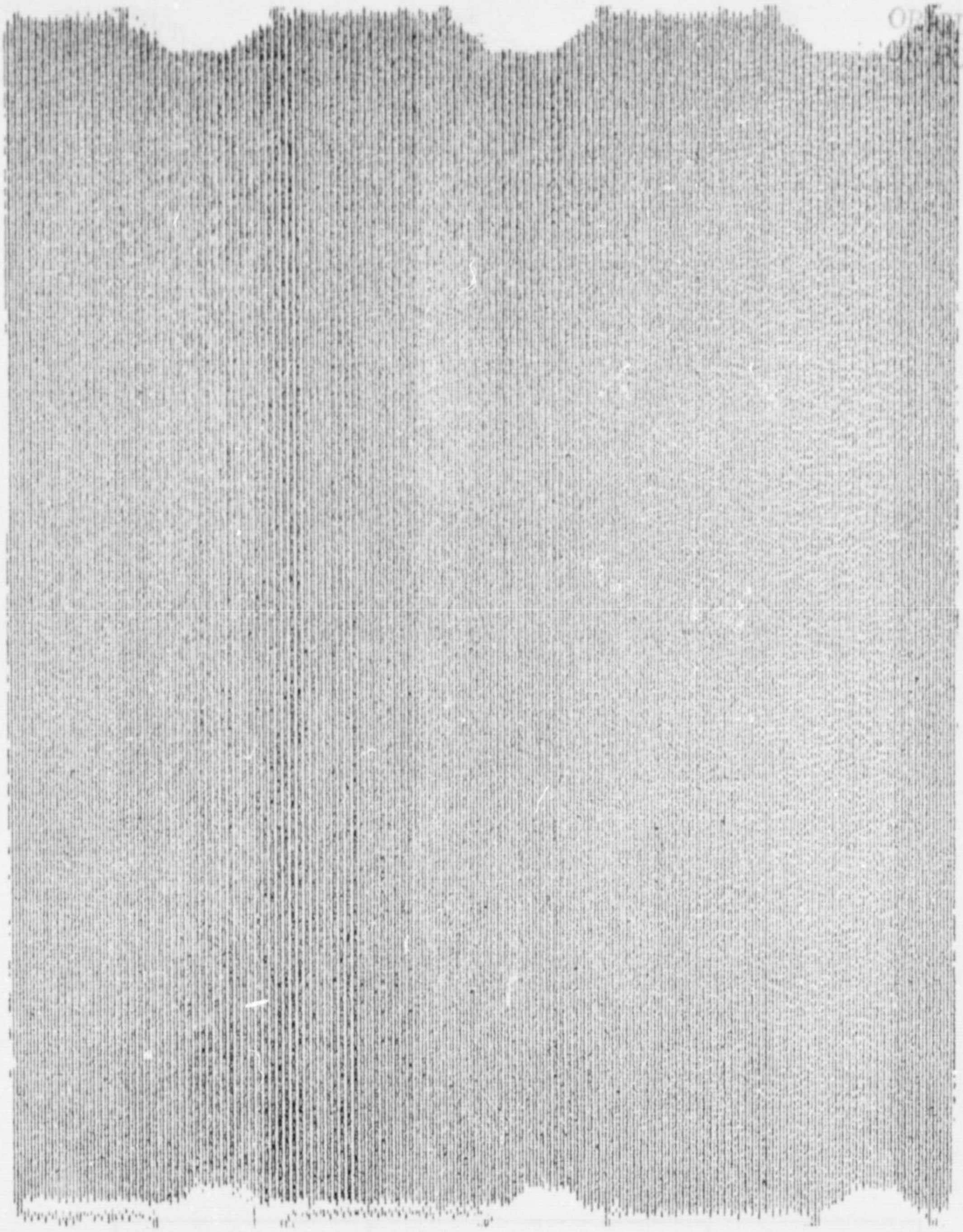
PANEL EX206	FORMULATION VARIABLES		PROCESS VARIABLES	
PREPREG RUN & (BATCH)	CONC. AP-22	CONC. ANHYDRIDES	COOK TIME	REFLUX TIME
4 (22946)	-5%	STD	STD	STD

Figure 16. C-Scan Resin Variable No. 4



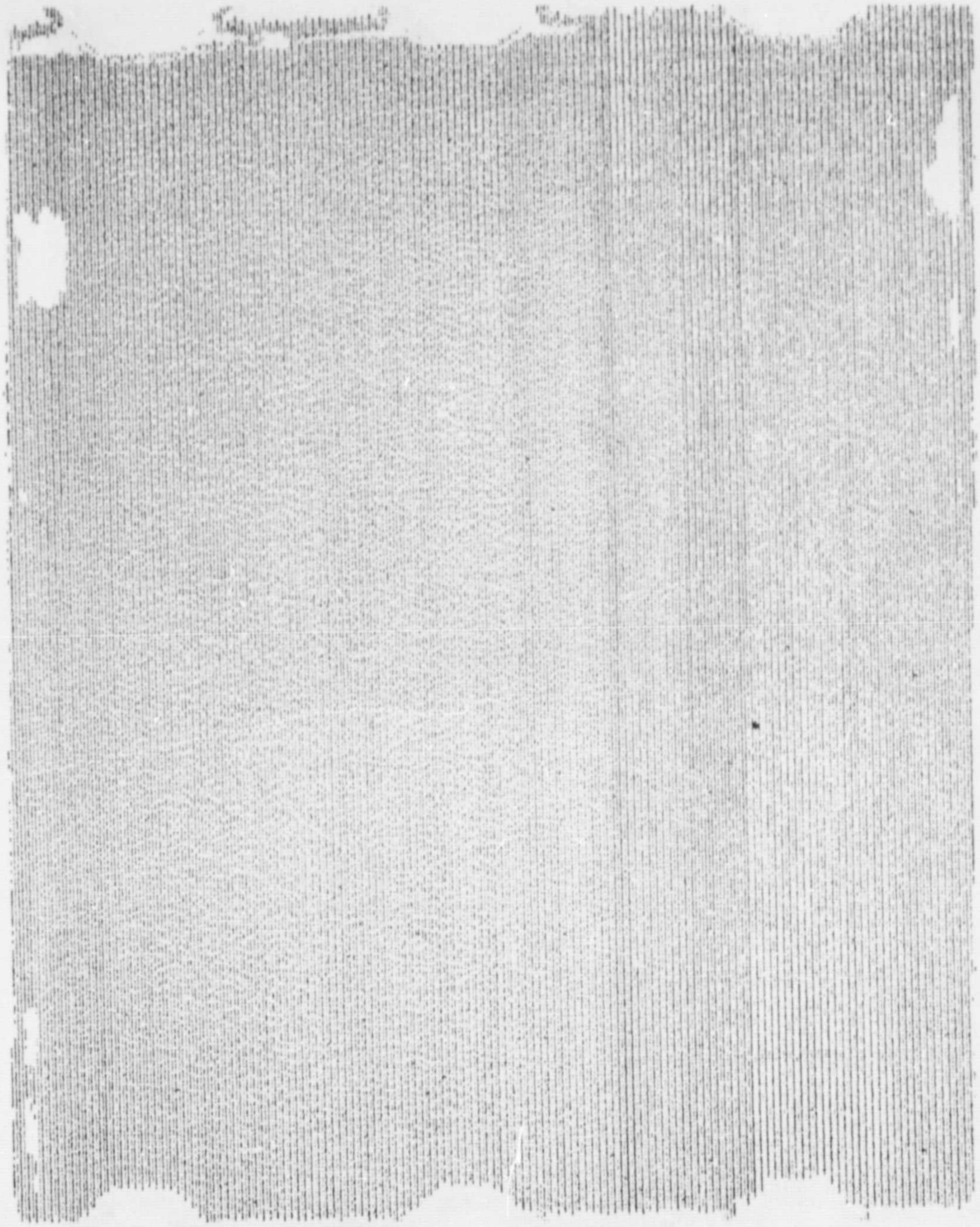
PANEL EX207	FORMULATION VARIABLES		PROCESS VARIABLES	
PREPREG RUN & (BATCH)	CONC. AP-22	CONC. ANHYDRIDES	COOK TIME	REFLUX TIME
5 (22947)	+10%	STD	STD	STD

Figure 17. C-Scan Resin Variable No. 5



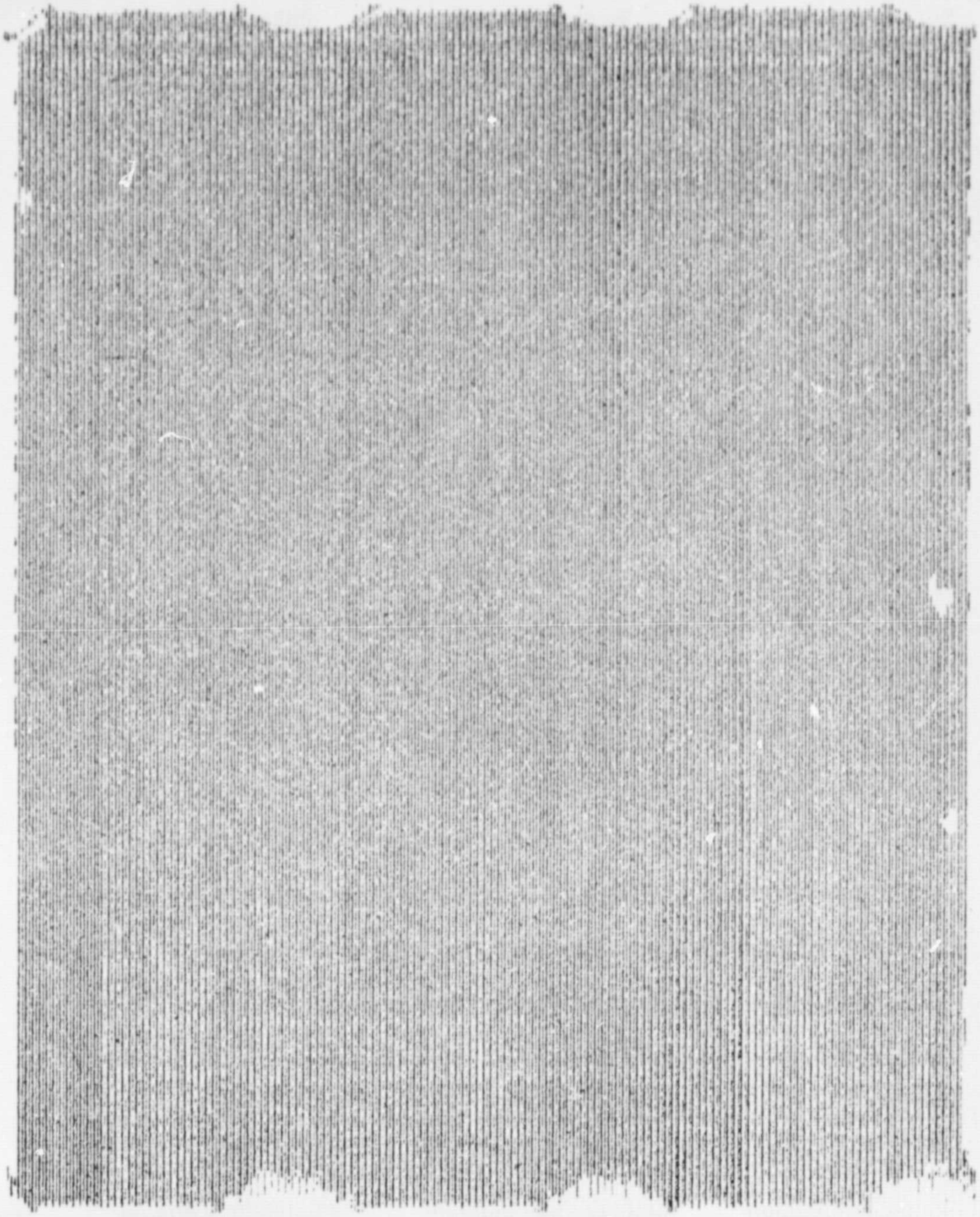
PANEL EX208	FORMULATION VARIABLES		PROCESS VARIABLES	
PREPREG RUN & (BATCH)	CONC. AP-22	CONC. ANHYDRIDES	COOK TIME	REFLUX TIME
6 (22948)	-10%	STD	STD	STD

Figure 18. C-Scan Resin Variable No. 6



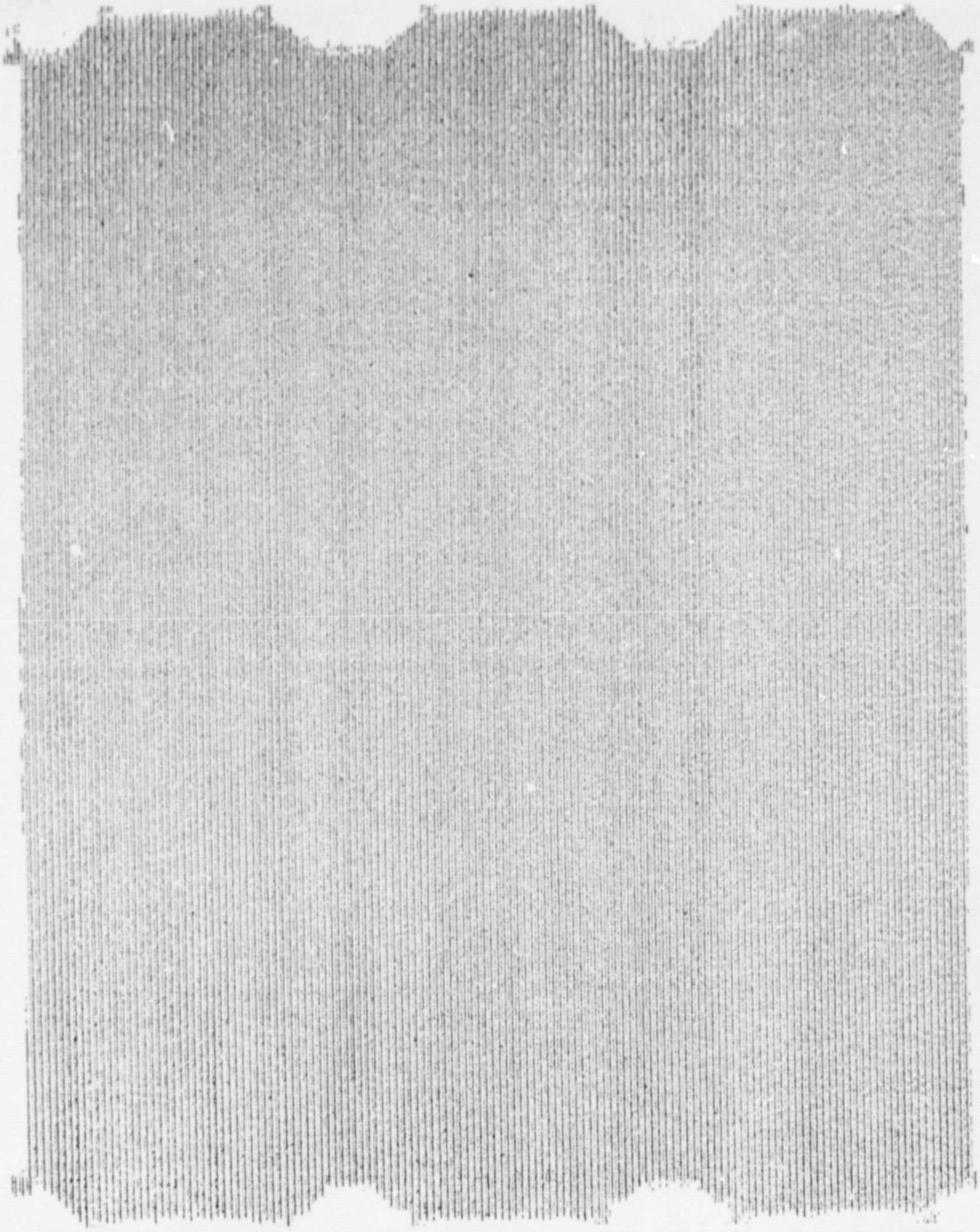
PANEL EX209	FORMULATION VARIABLES		PROCESS VARIABLES	
PREPREG RUN & (BATCH)	CONC. AP-22	CONC. ANHYDRIDES	COOK TIME	REFLUX TIME
7 (22949)	STD	NA (+5%) BTDA (STD)	STD	STD

Figure 19. C-Scan Resin Variable No. 7



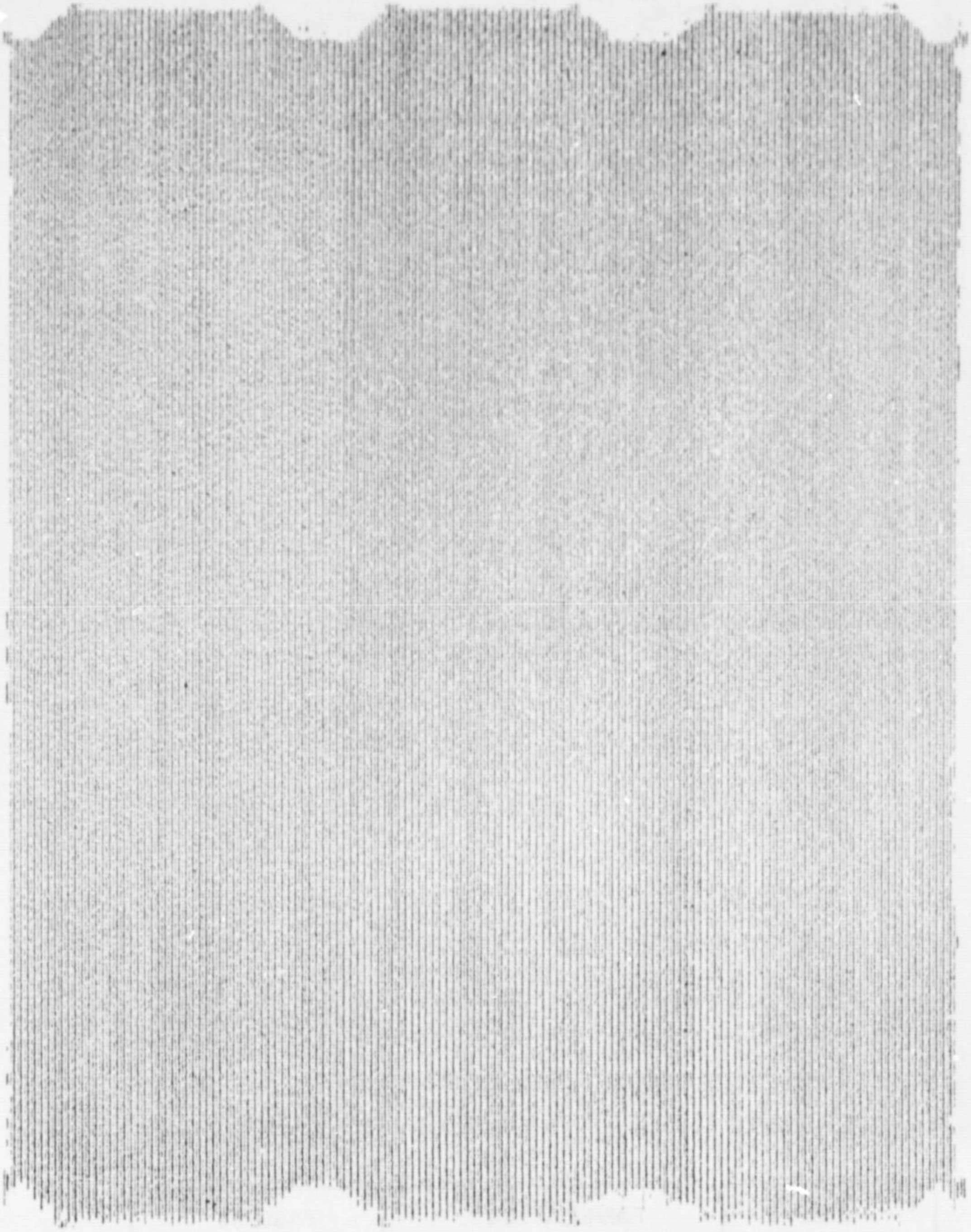
PANEL EX210	FORMULATION VARIABLES		PROCESS VARIABLES	
PREPREG RUN & (BATCH)	CONC. AP-22	CONC. ANHYDRIDES	COOK TIME	REFLUX TIME
8 (22950)	STD	NA (-5%) BTDA (STD)	STD	STD

Figure 20. C-Scan Resin Variable No. 8



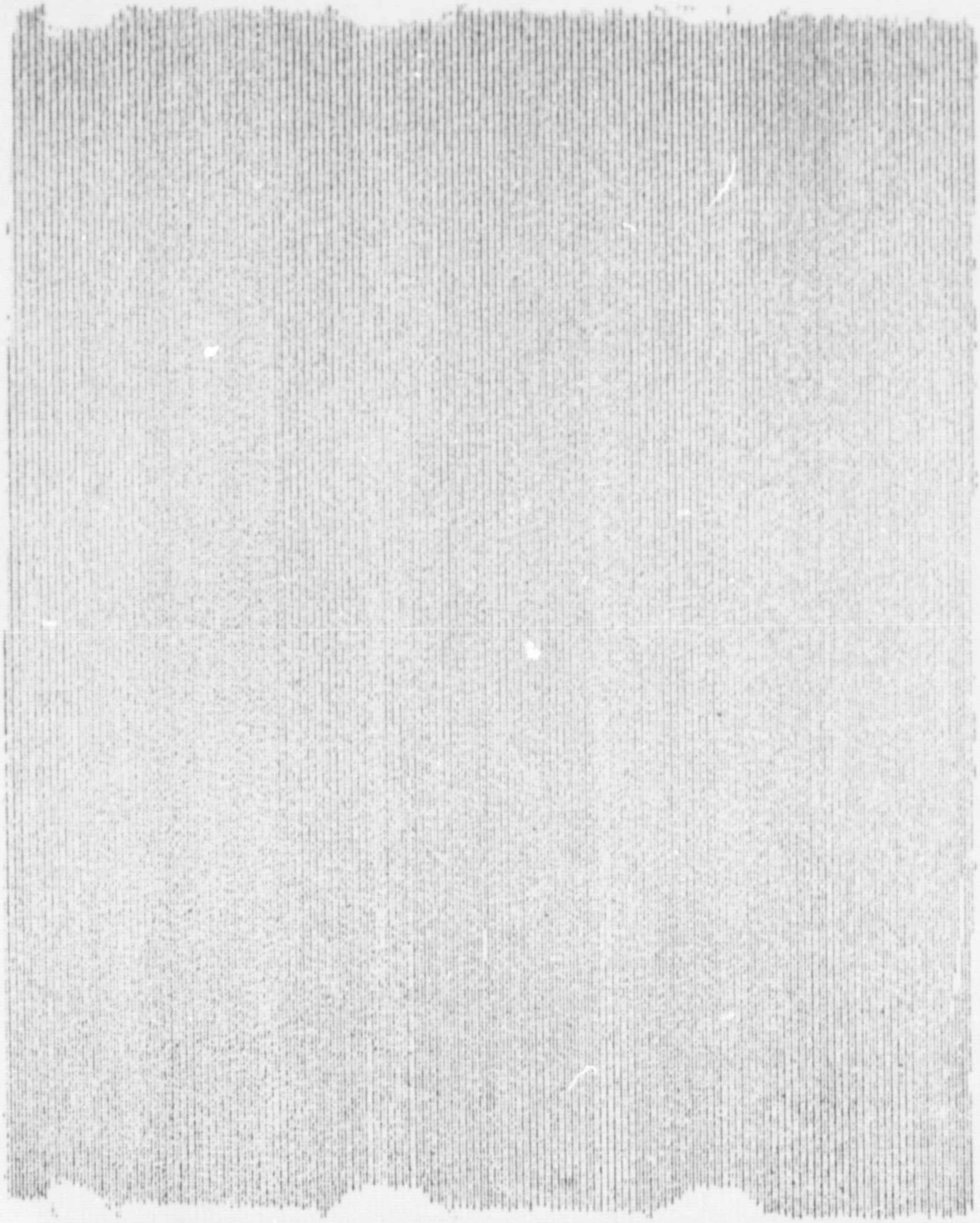
PANEL EX211	FORMULATION VARIABLES		PROCESS VARIABLES	
PREPREG RUN & (BATCH)	CONC. AP-22	CONC. ANHYDRIDES	COOK TIME	REFLUX TIME
9 (22951)	STD	NA (STD) BTDA (+5%)	STD	STD

Figure 21. C-Scan Resin Variable No. 9



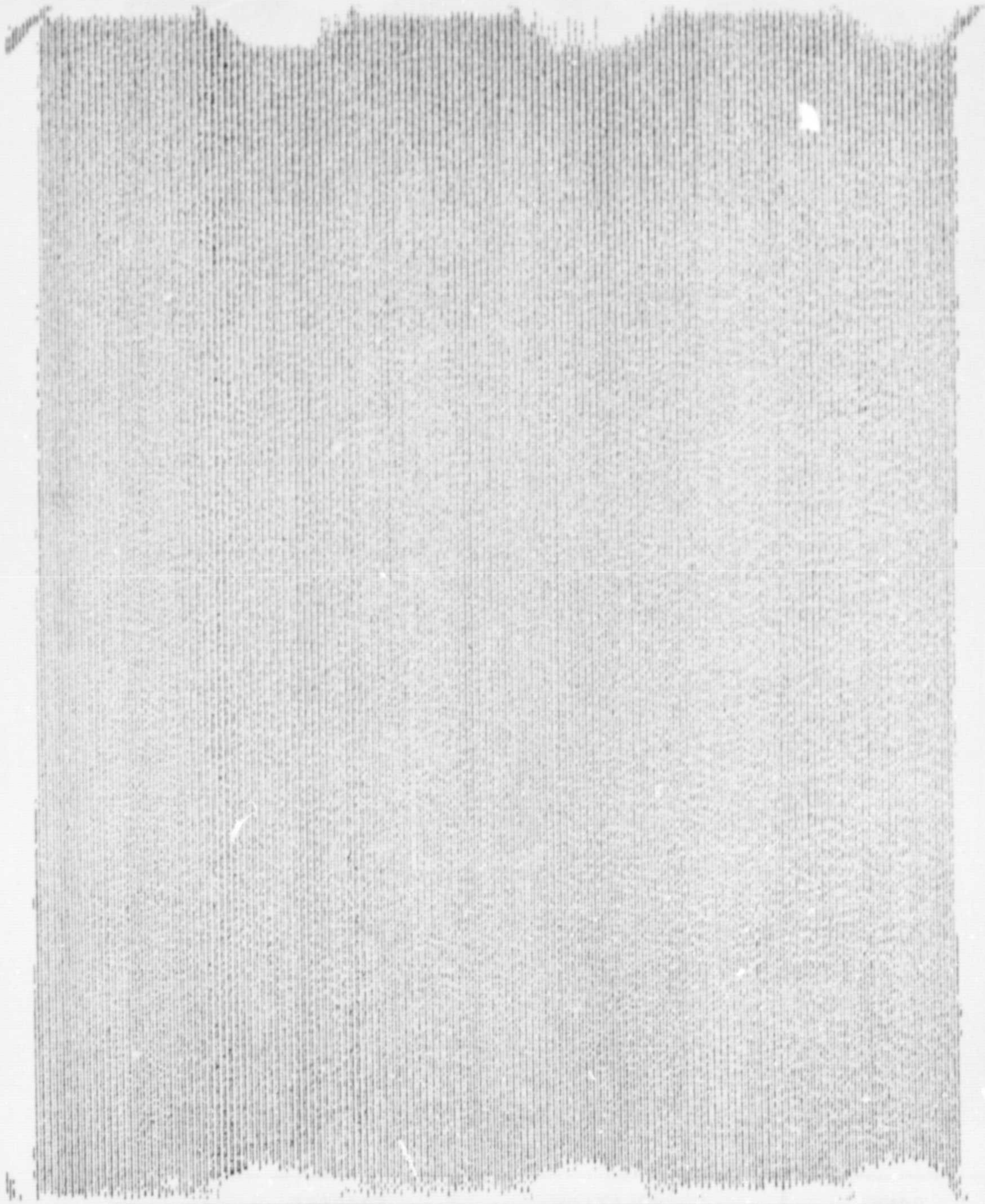
PANEL EX212	FORMULATION VARIABLES		PROCESS VARIABLES	
PREPREG RUN & (BATCH)	CONC. AP-22	CONC. ANHYDRIDES	COOK TIME	REFLUX TIME
10 (22952)	STD	NA (STD) BTDA (-5%)	STD	STD

Figure 22. C-Scan Resin Variable No. 10



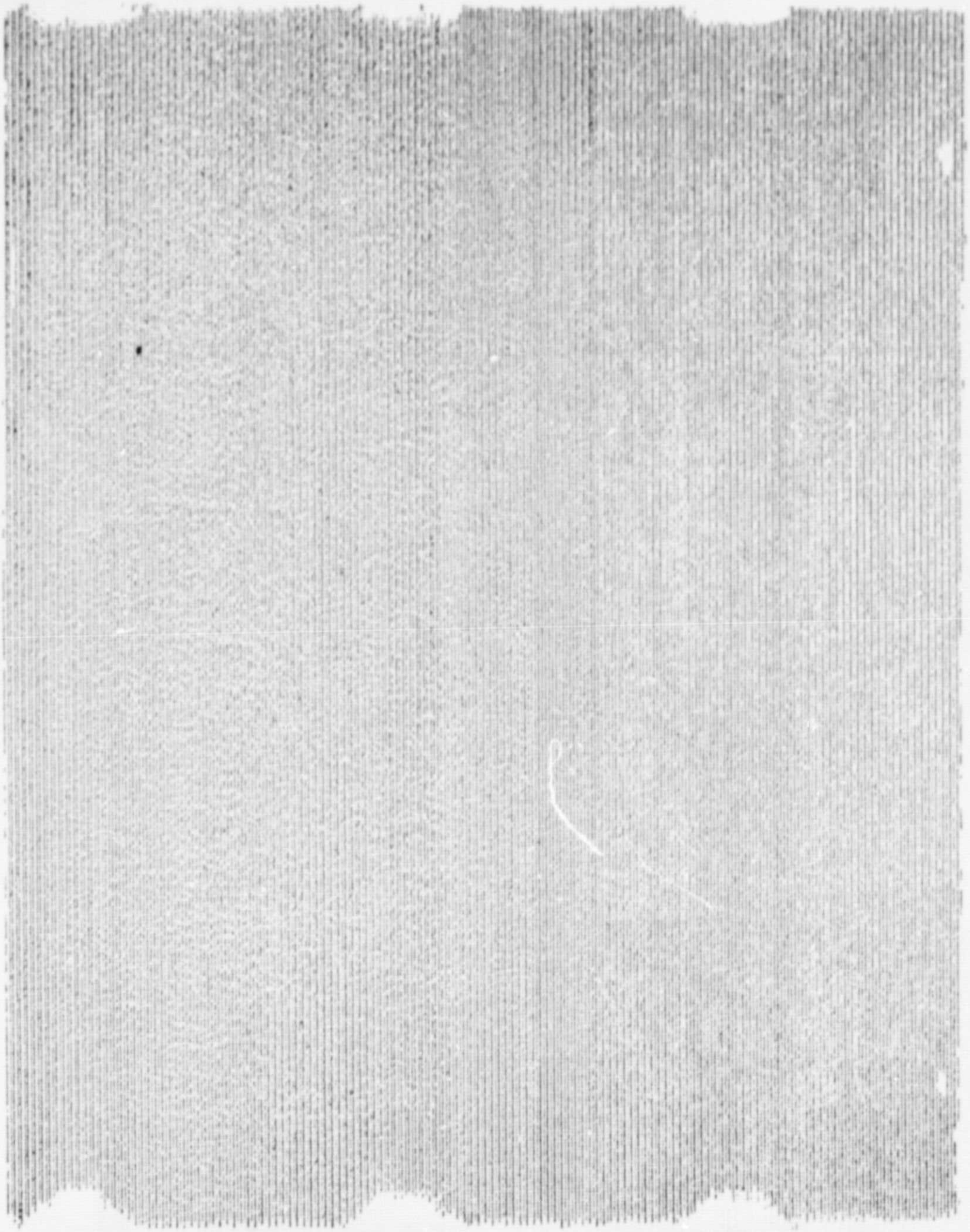
PANEL EX213	FORMULATION VARIABLES		PROCESS VARIABLES	
PREPREG RUN & (BATCH)	CONC. AP-22	CONC. ANHYDRIDES	COOK TIME	REFLUX TIME
11 (22953)	STD	STD	2HRS @ 79C	STD

Figure 23. C-Scan Resin Variable No. 11



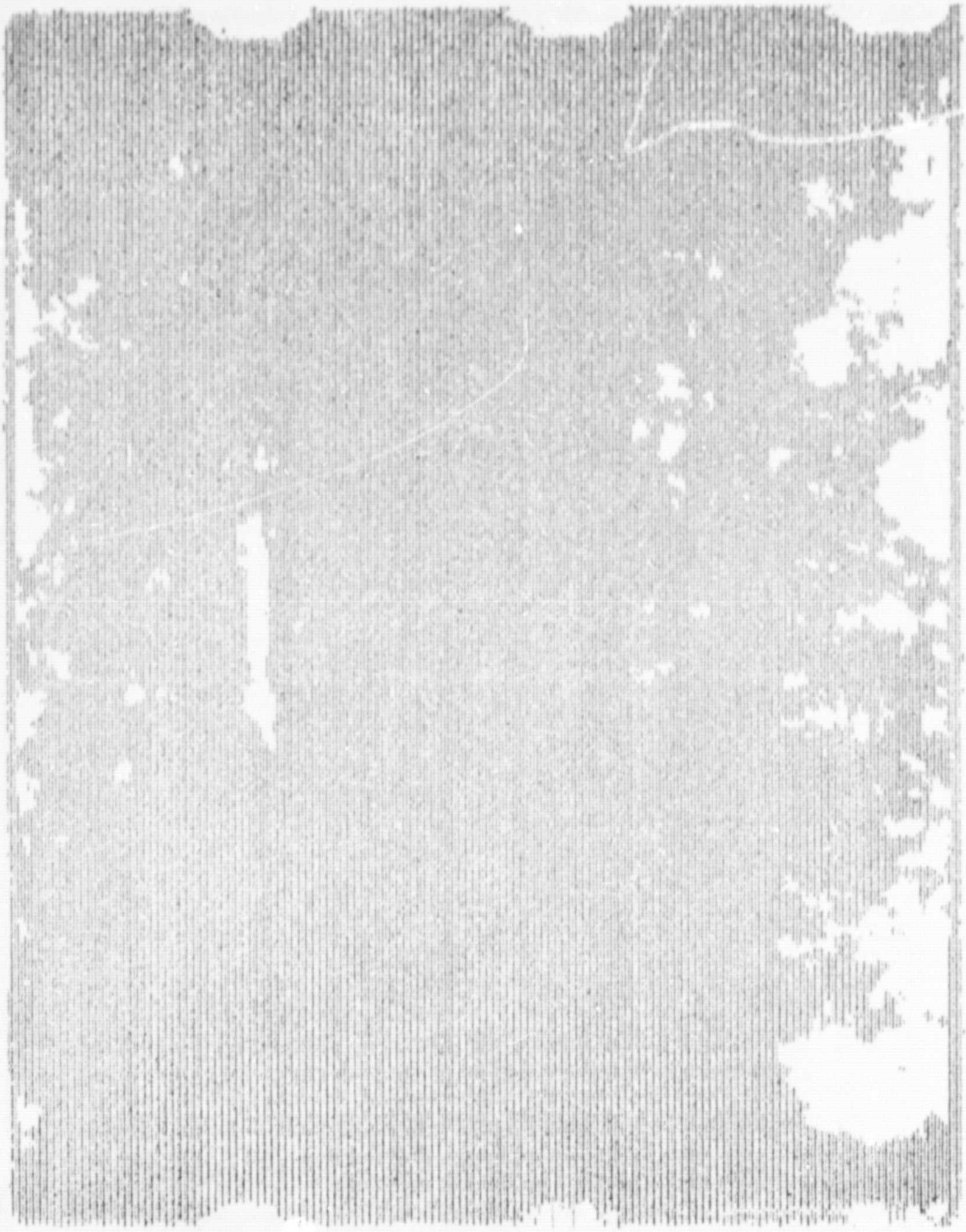
PANEL EX214	FORMULATION VARIABLES		PROCESS VARIABLES	
PREPREG RUN & (BATCH)	CONC. AP-22	CONC. ANHYDRIDES	COOK TIME	REFLUX TIME
12 (22954)	STD	STD	2HRS @ 60C	STD

Figure 24. C-Scan Resin Variable No. 12



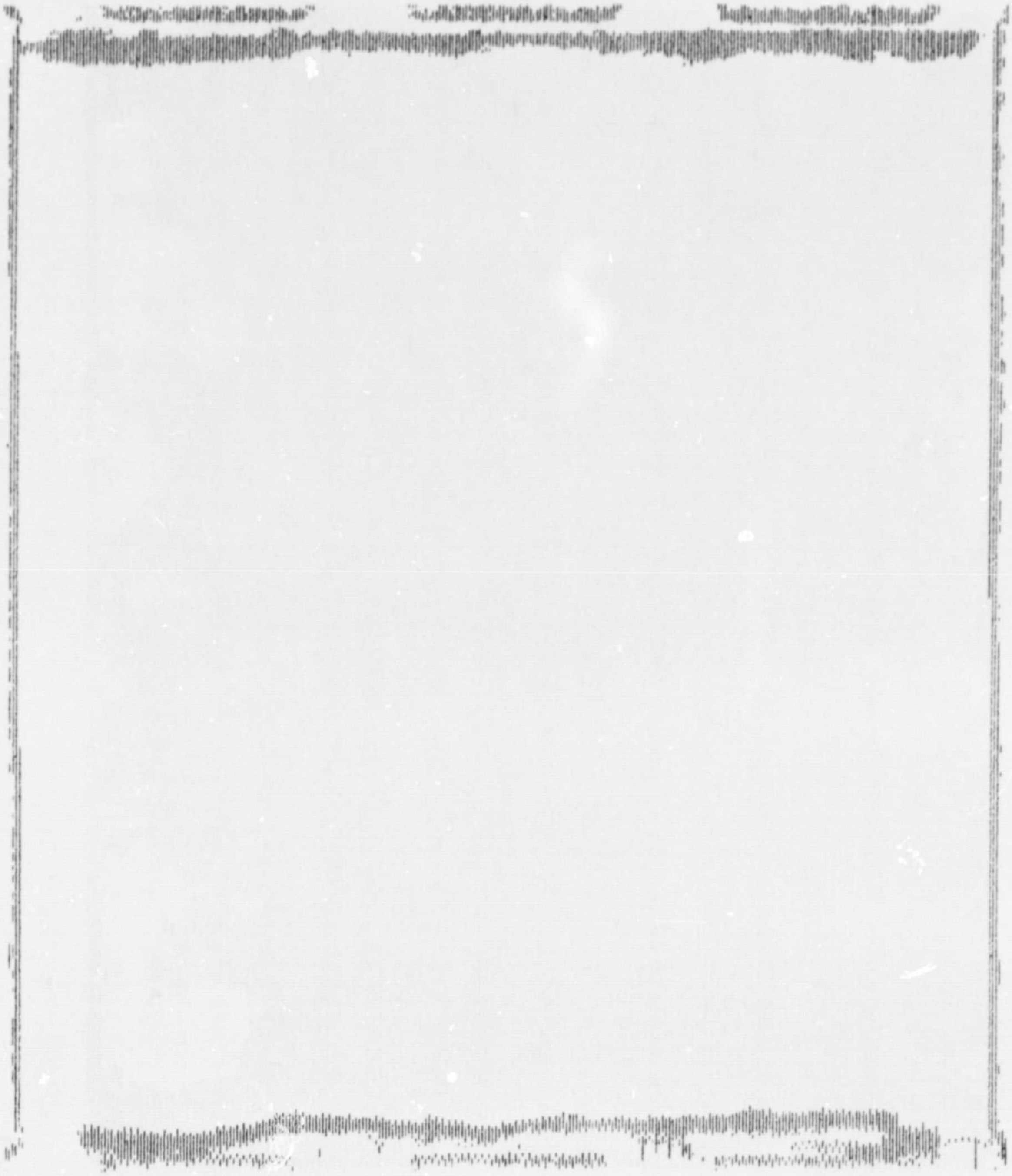
PANEL EX215	FORMULATION VARIABLES		PROCESS VARIABLES	
PREPREG RUN & (BATCH)	CONC. AP-22	CONC. ANHYDRIDES	COOK TIME	REFLUX TIME
13 (22955)	STD	STD	STD	6 HRS

Figure 25. C-Scan Resin Variable No. 13



PANEL EX216	FORMULATION VARIABLES		PROCESS VARIABLES	
PREPREG RUN & (BATCH)	CONC. AP-22	CONC. ANHYDRIDES	COOK TIME	REFLUX TIME
14 (23107)	STD ANCH-AMINE DL	STD	STD	STD

Figure 26. C-Scan Resin Variable No. 14



PANEL EX219	FORMULATION VARIABLES		PROCESS VARIABLES	
PREPREG RUN & (BATCH)	CONC. AP-22	CONC. ANHYDRIDES	COOK TIME	REFLUX TIME
15 (23236)	STD TONOX 22	STD	STD	STD

Figure 27. C-Scan Resin Variable No. 15

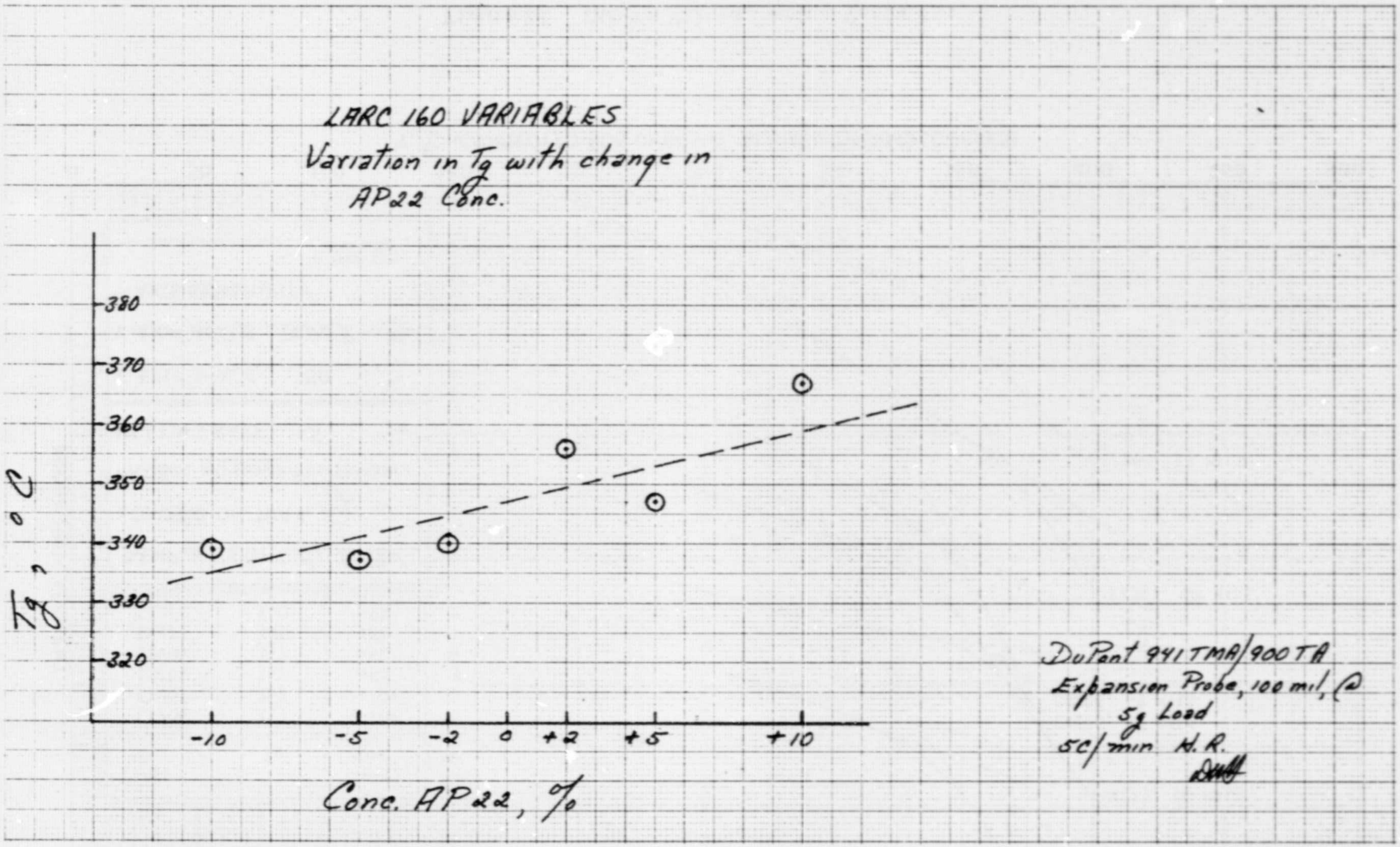


Figure 28 Variation in Tg With Change in AP22 Concentration

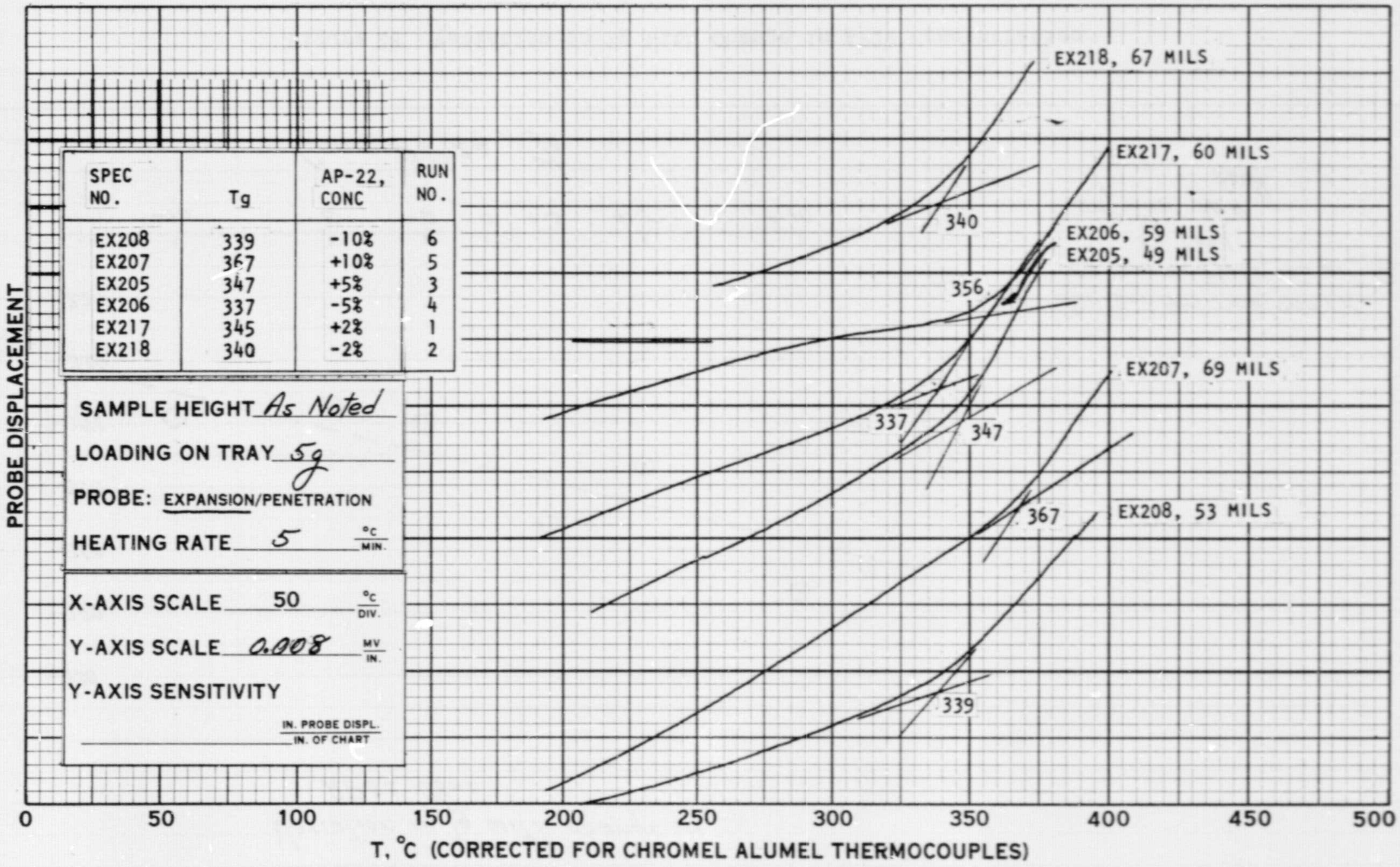


Figure 29. TMA-Tg Values, Amine Variables

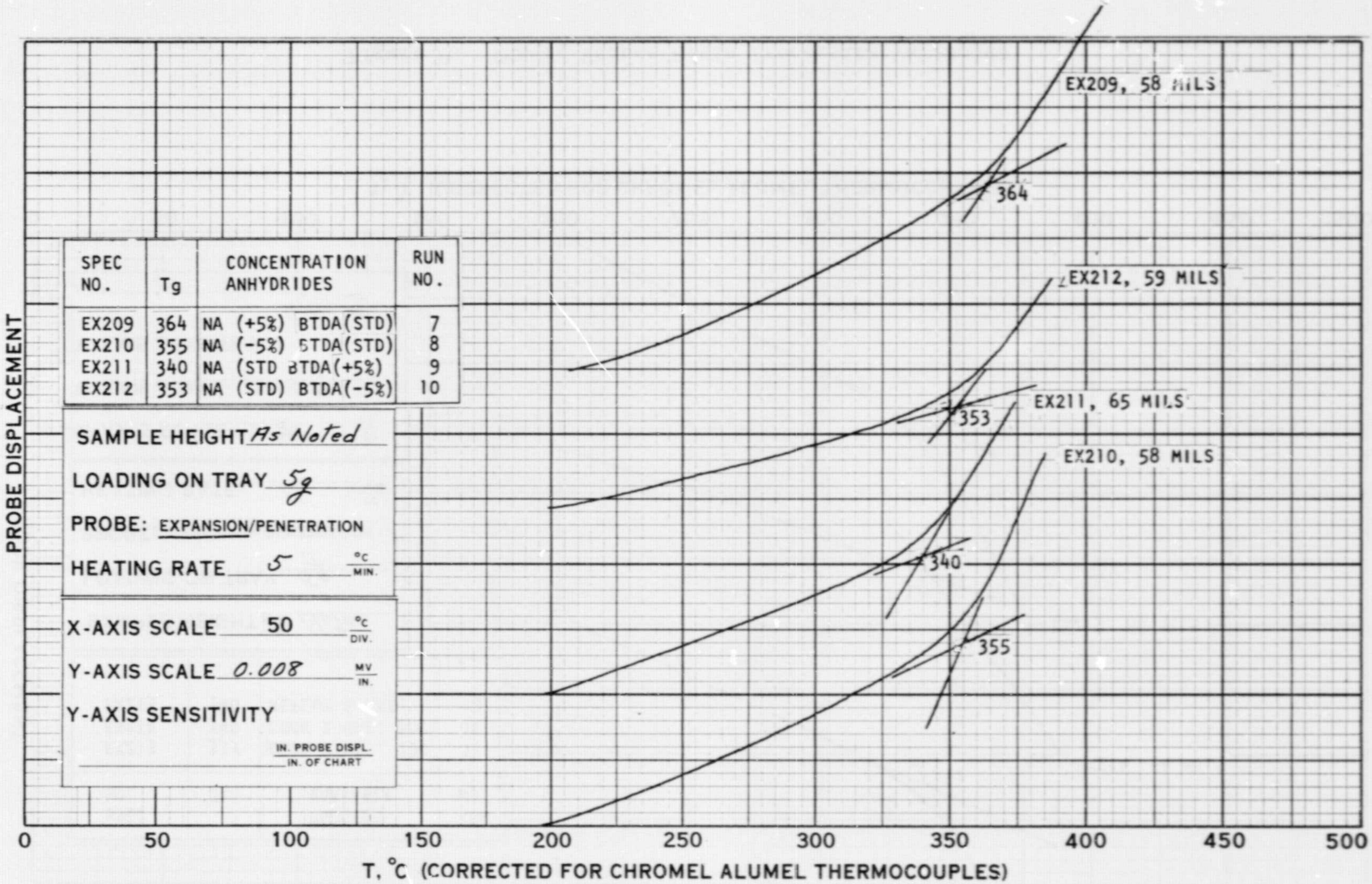


Figure 30. TMA-Tg Values NA-BTDA Variables

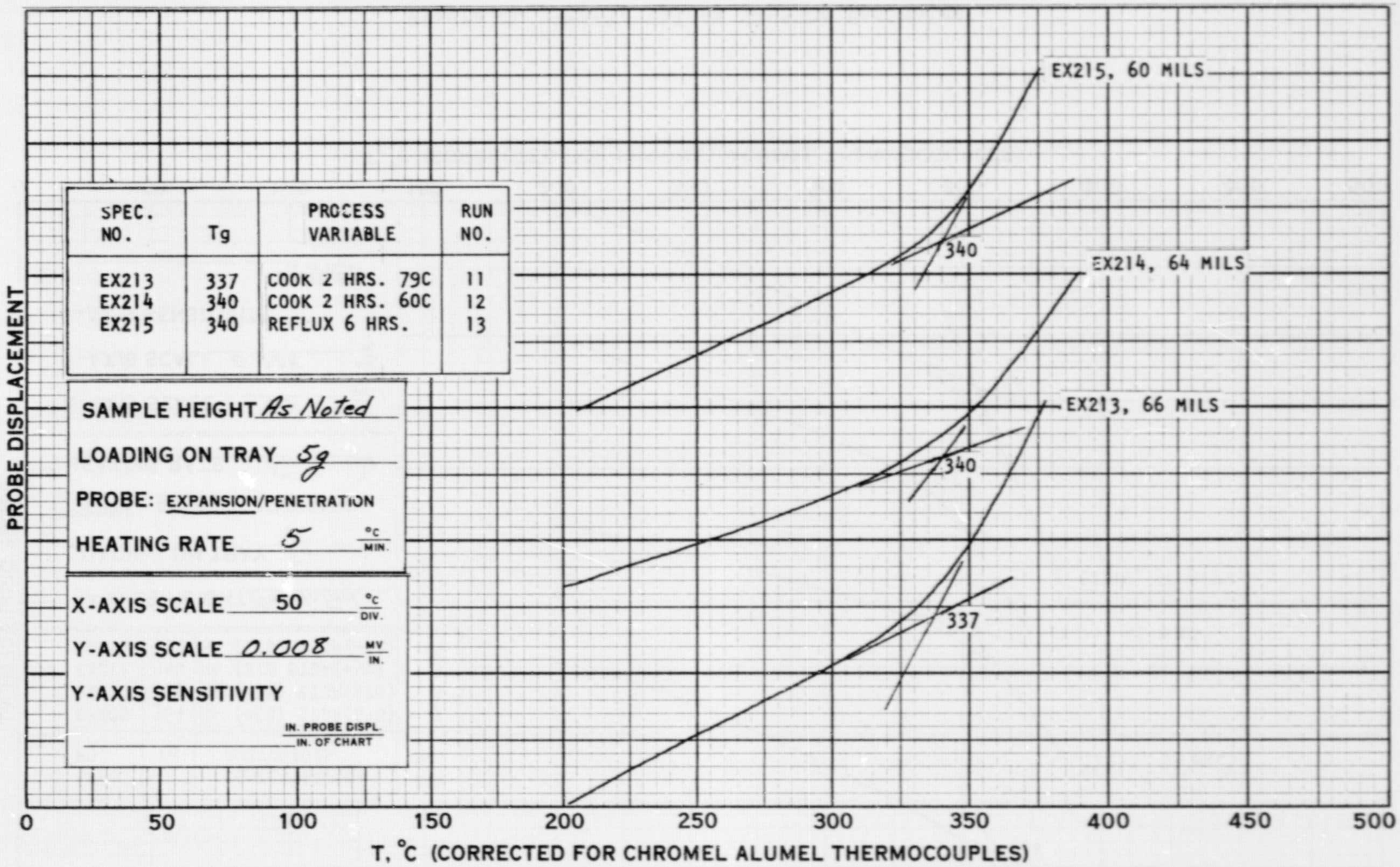


Figure 31. TMA-Tg Values Resin Processing Variables

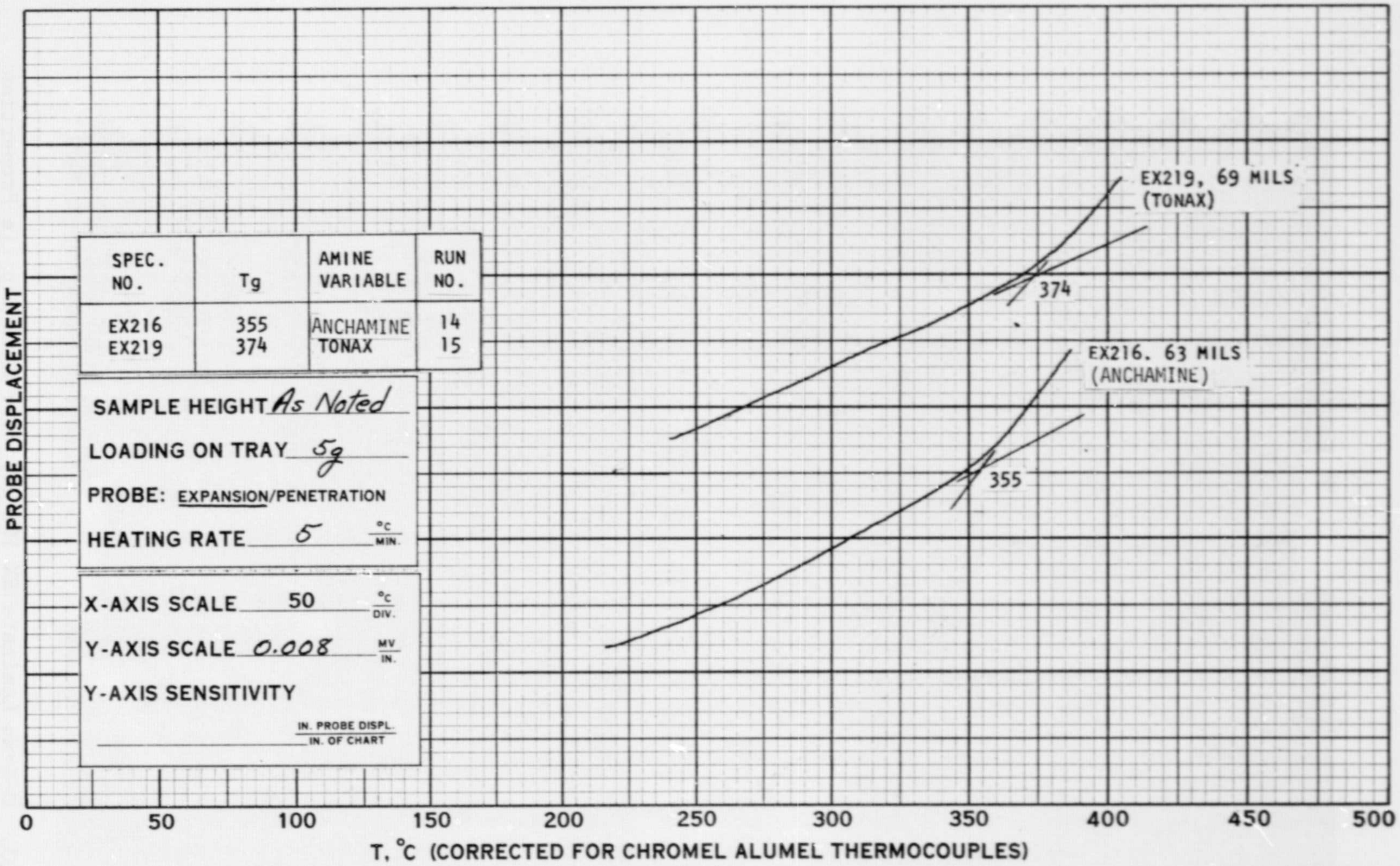


Figure 32. TMA-Tg Values Anchamine & Tonax Amines

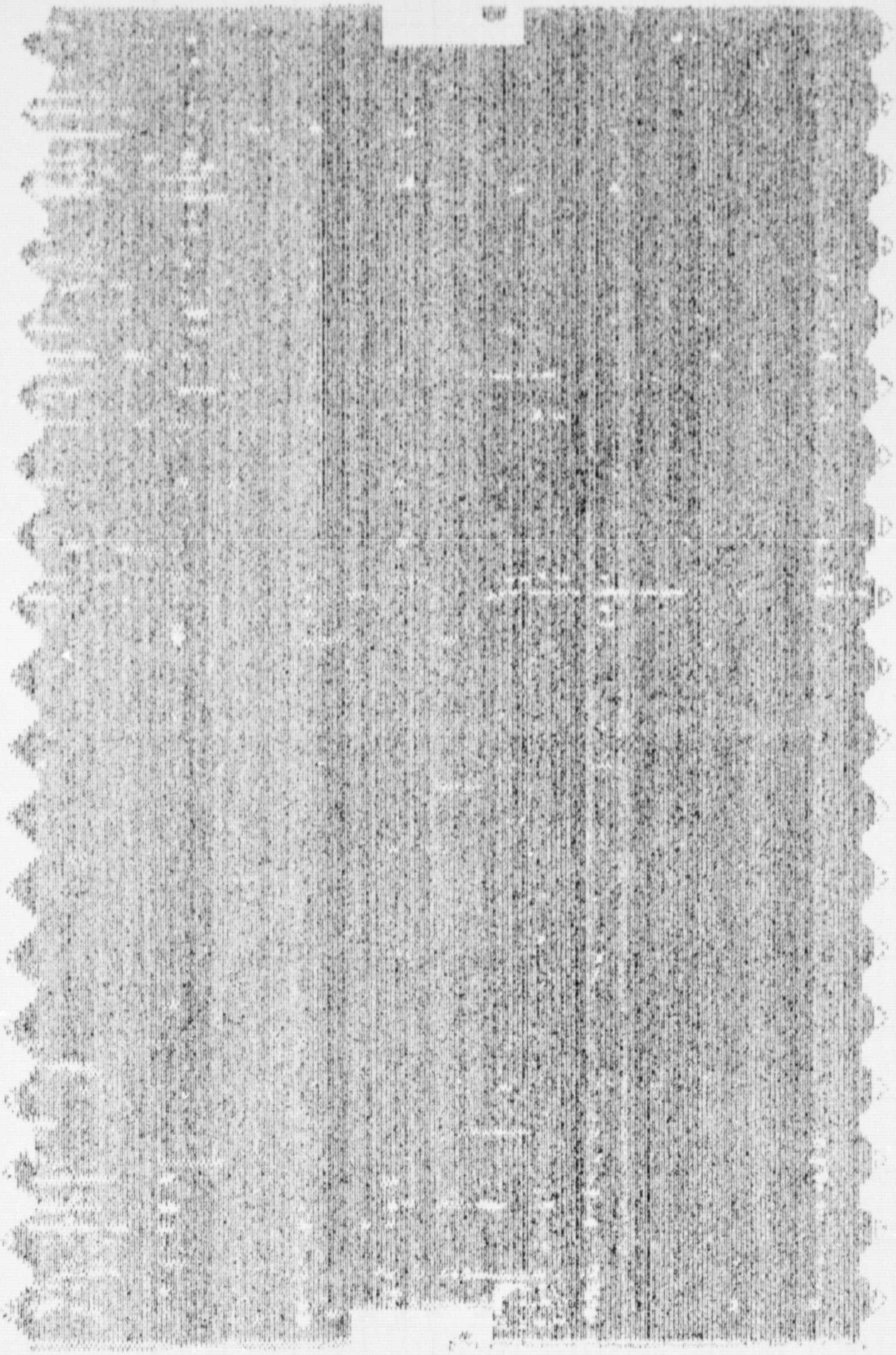


Figure 33. C-Scan Laminate EX 199 $(0)_s$ for Aged Tensile Properties

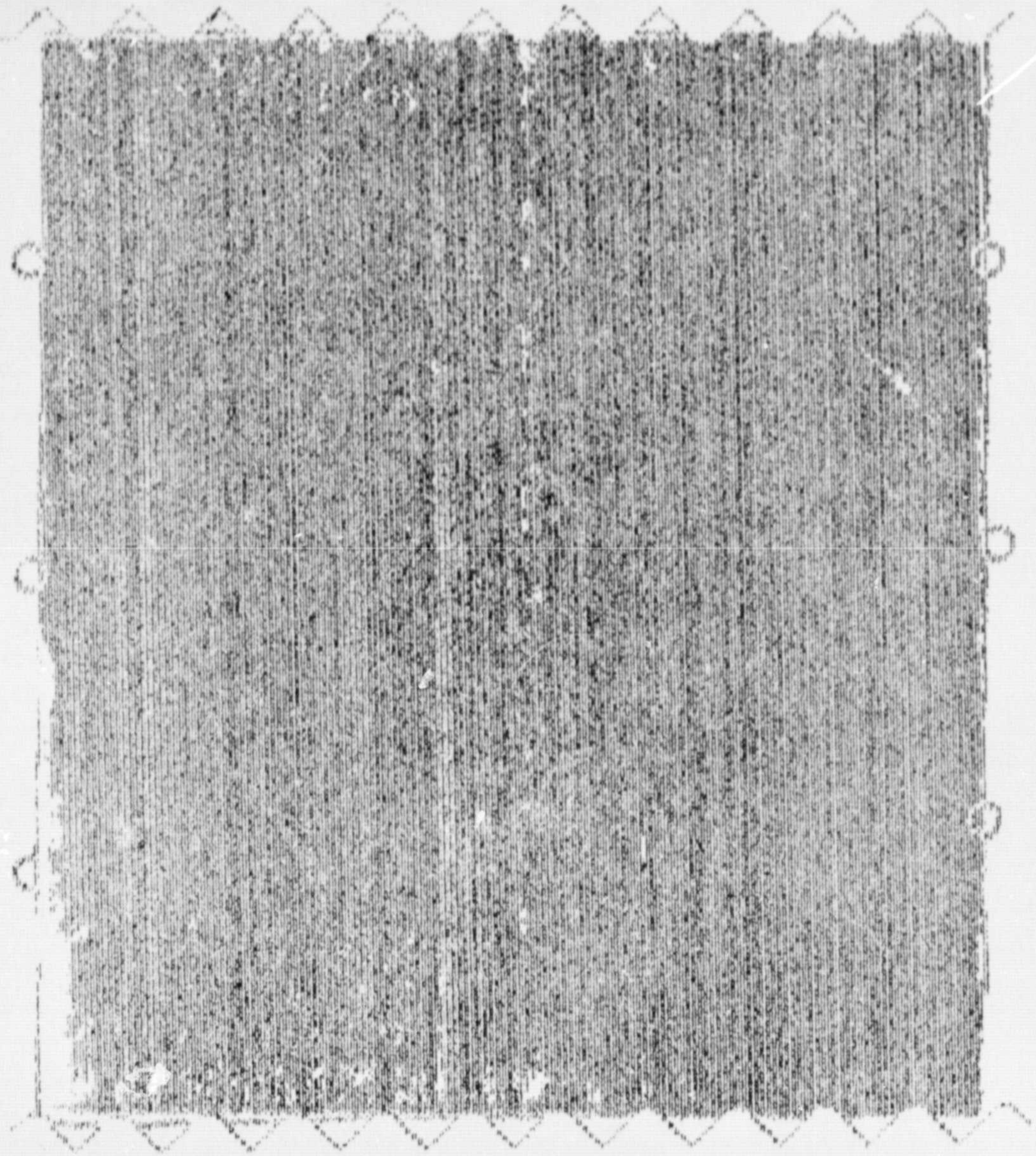


Figure 34. C-Scan Laminate EX 200 $(0,\pm45,90)_s$ for Aged Tensile Properties

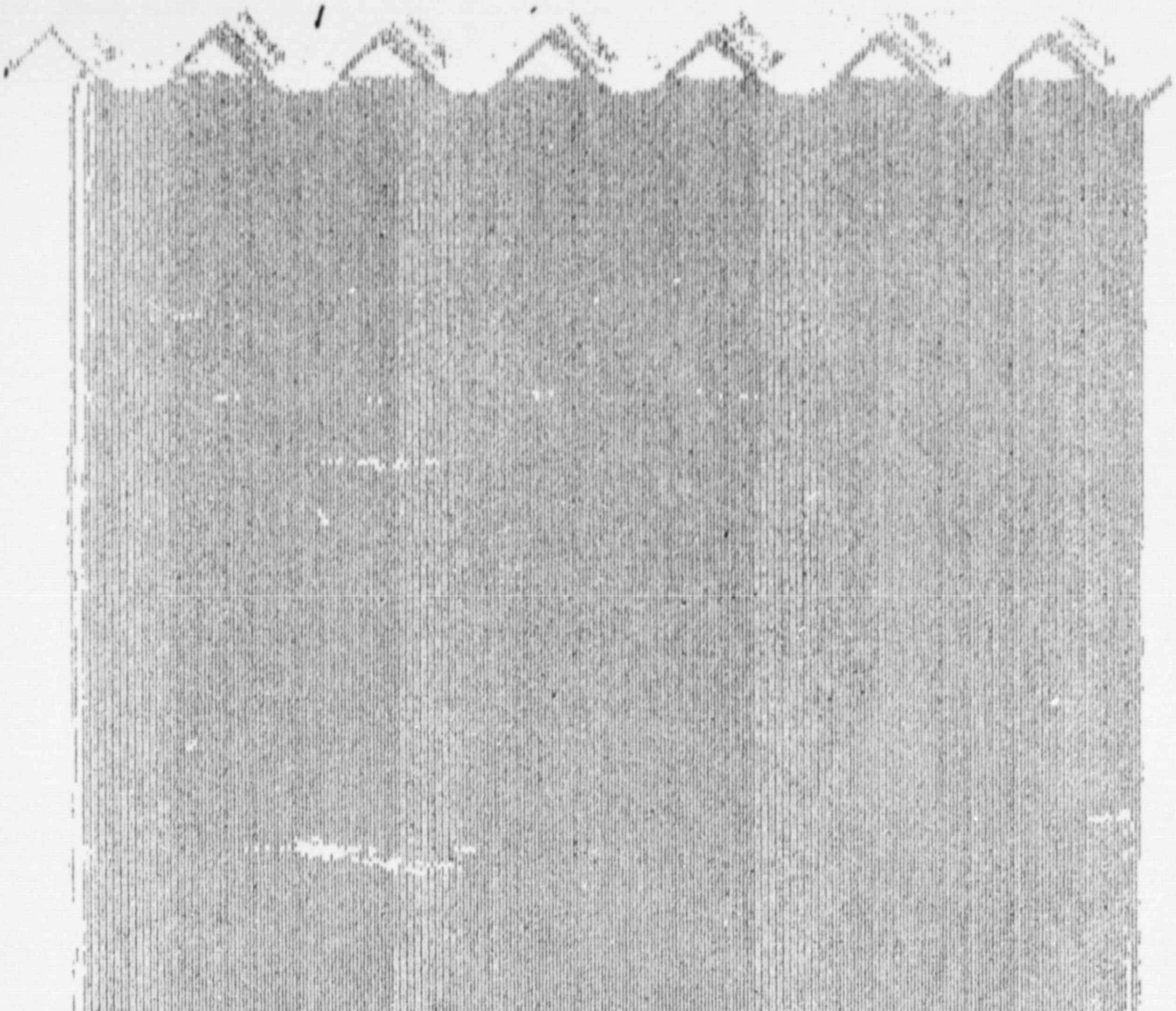


Figure 35. C-Scan Laminate EX 201 $(90)_{40}$ for Aged Tensile and Compressive Properties

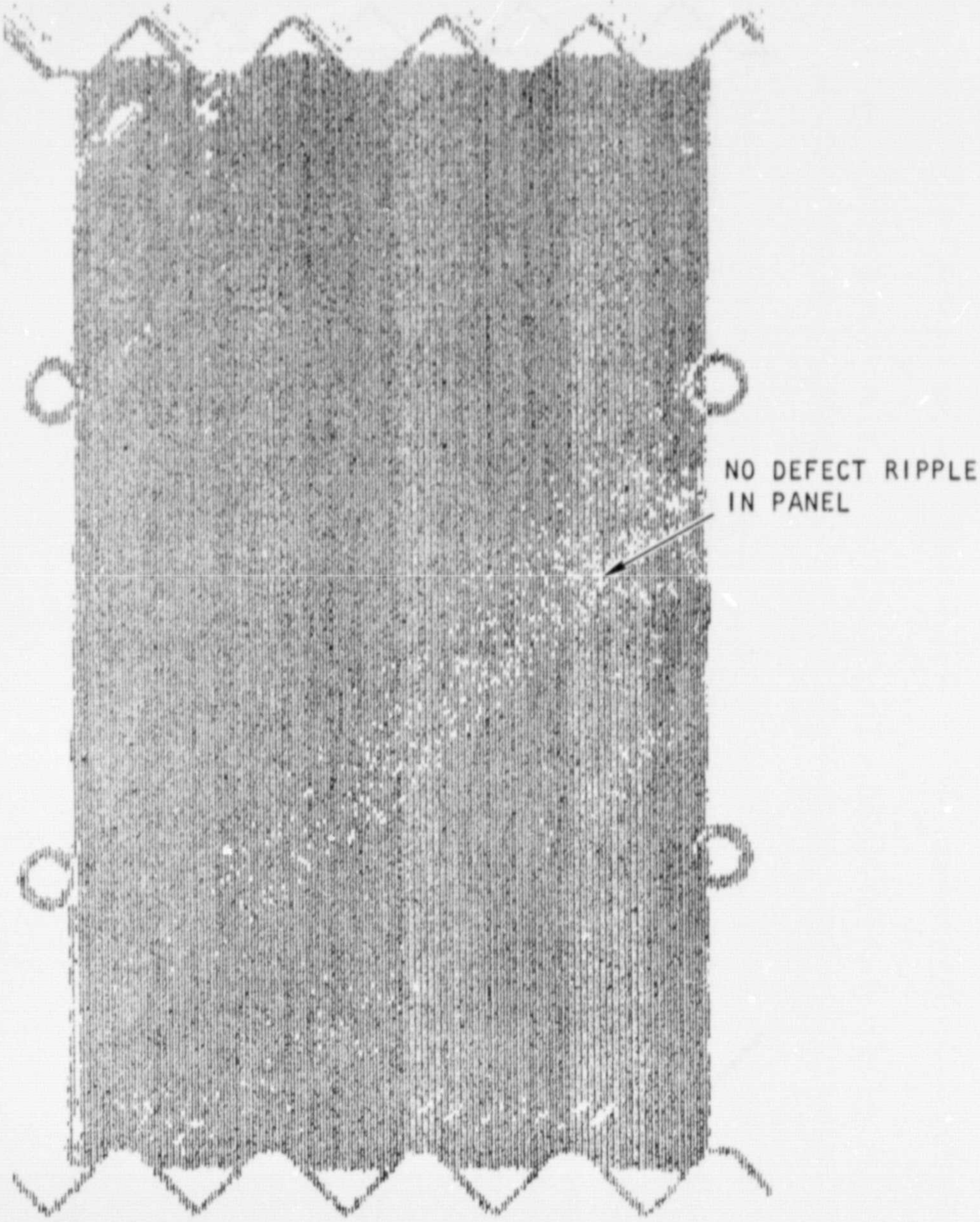


Figure 36. C-Scan Laminate EX202 $(\pm 45)_s$ for Aged Tensile Properties

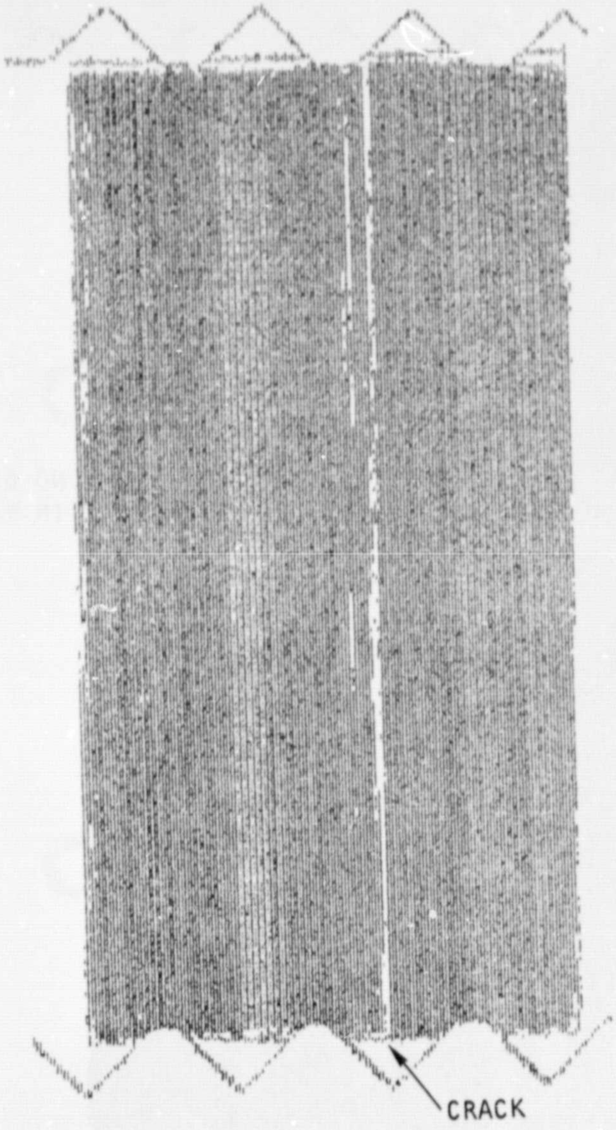


Figure 37. C-Scan Laminate EX 204 $(0)_{26}$ for Aged Short Beam Shear and Flexural Properties

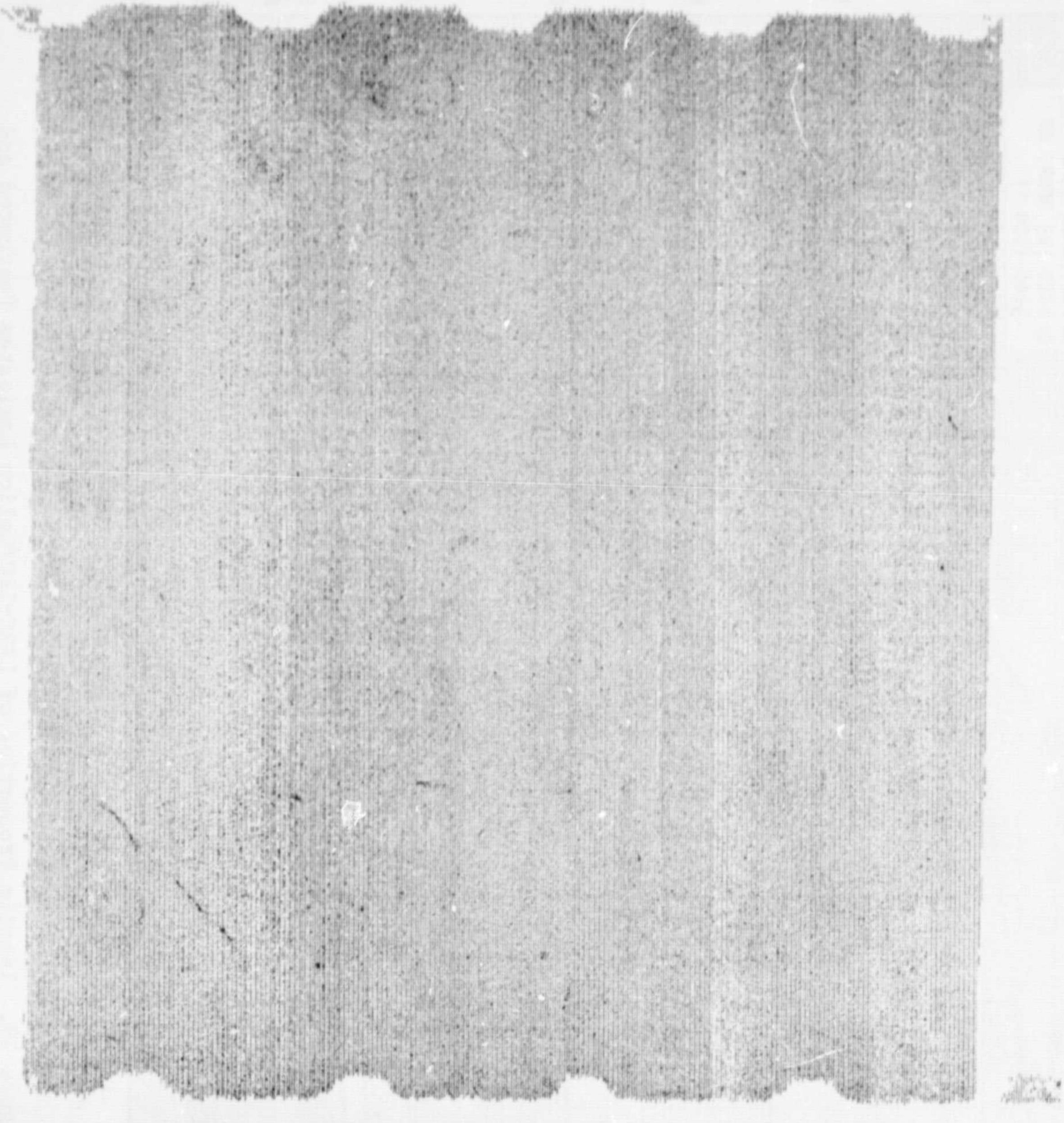


Figure 38. C-Scan Laminate EX 220 $(\pm 45)_s$ 32 Ply for Aged Compressive Properties

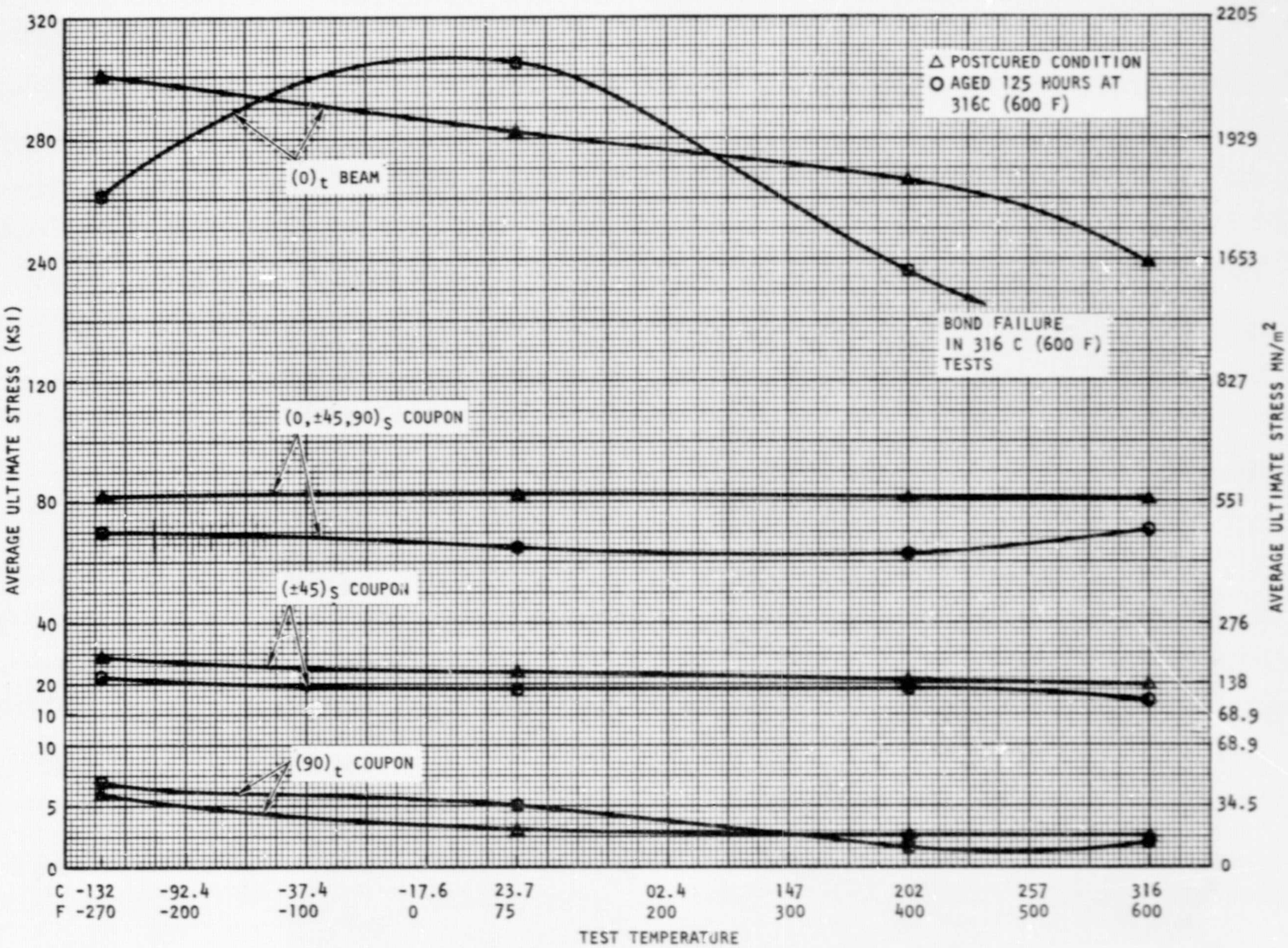


Figure 39. Tensile Properties of LARC-160/Celion Laminates Postcured and 125 Hours -316 C (600 F) Aged Conditions

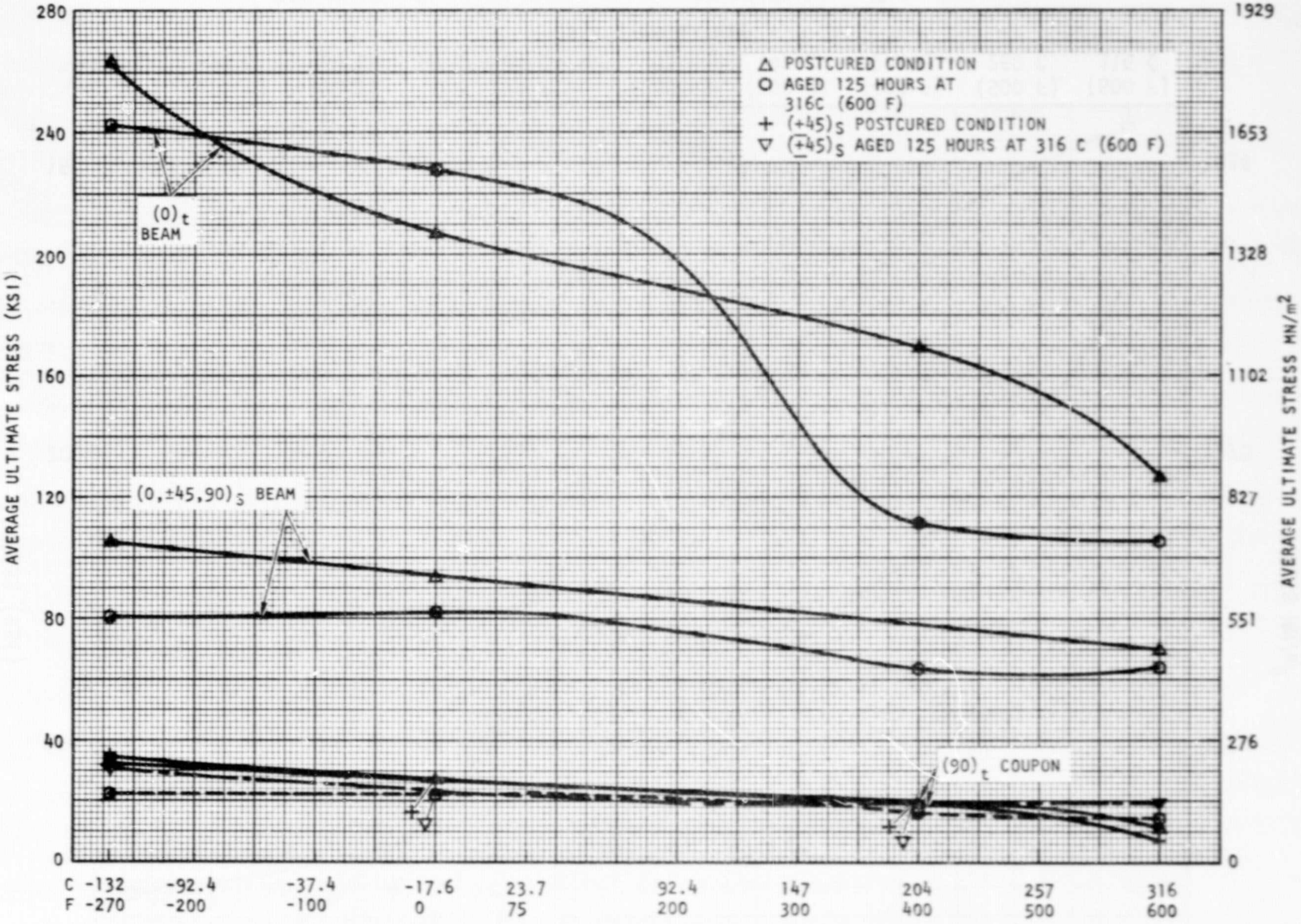


Figure 40. Compression Properties of LARC-160/Celion Laminates Postcured and 125 Hours -316 C (600 F) Aged Conditions

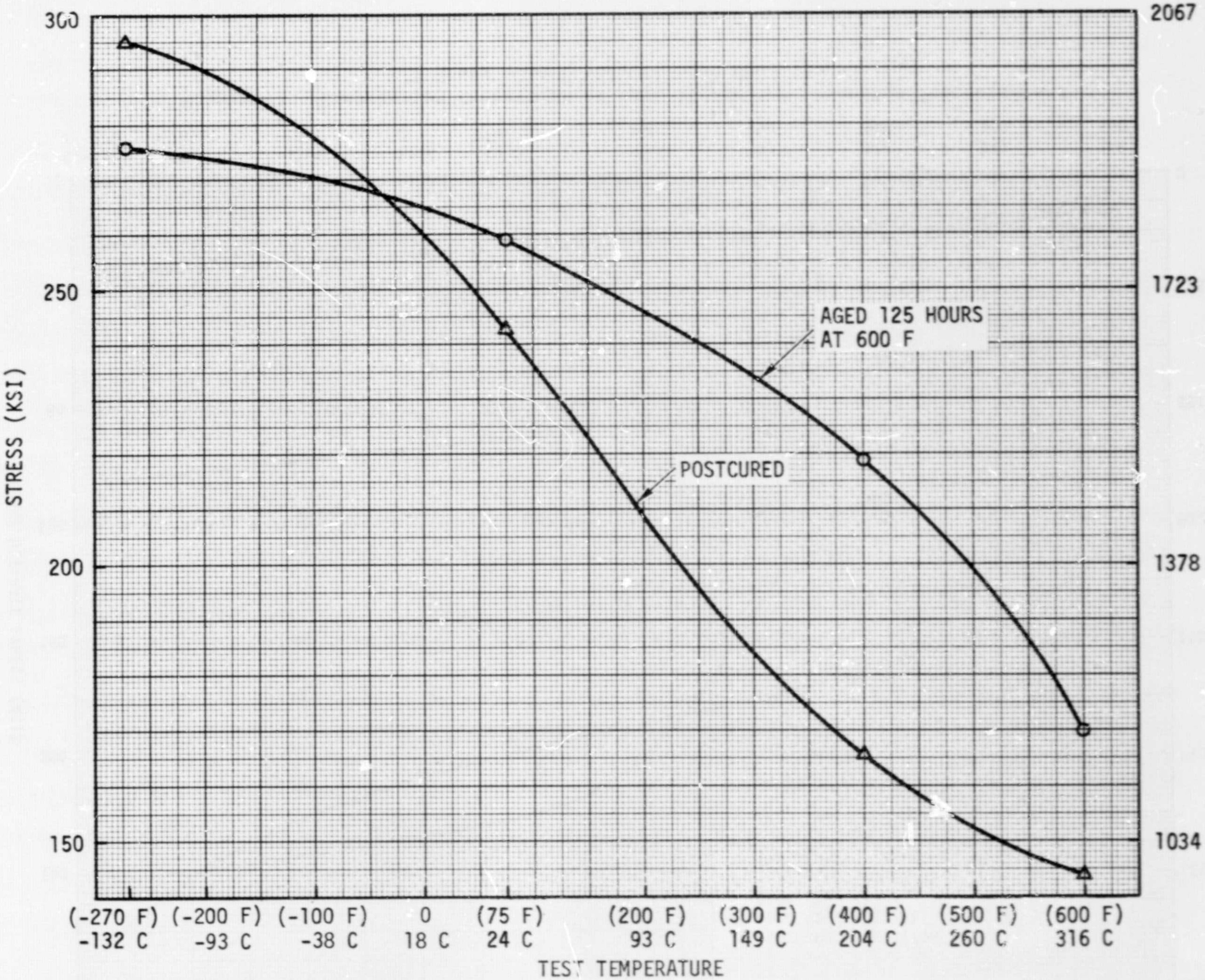


Figure 41. Flexural Strength of LARC-160/Celion 0° Laminates

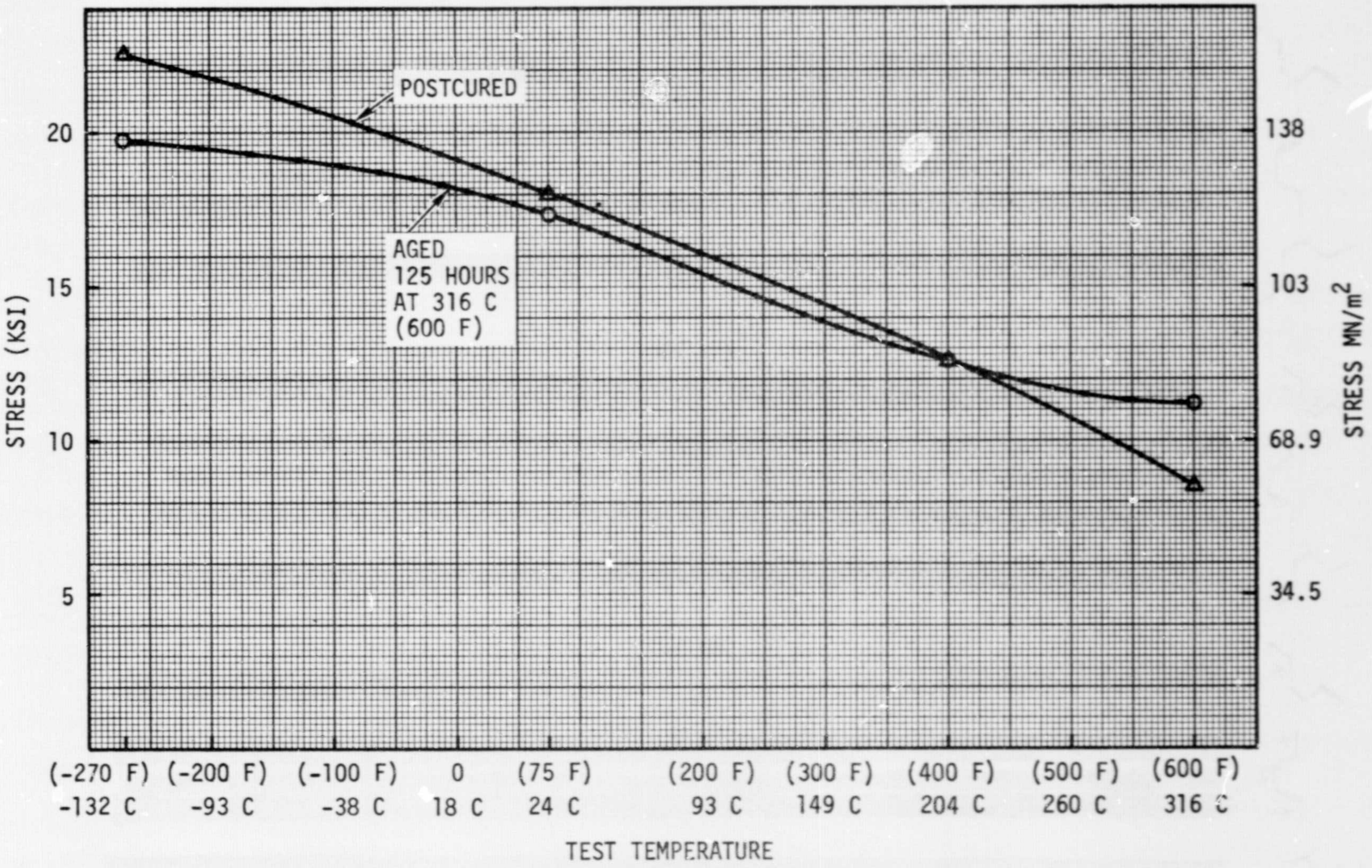


Figure 42. Short Beam Shear Strength of LARC-160/Celion Laminates

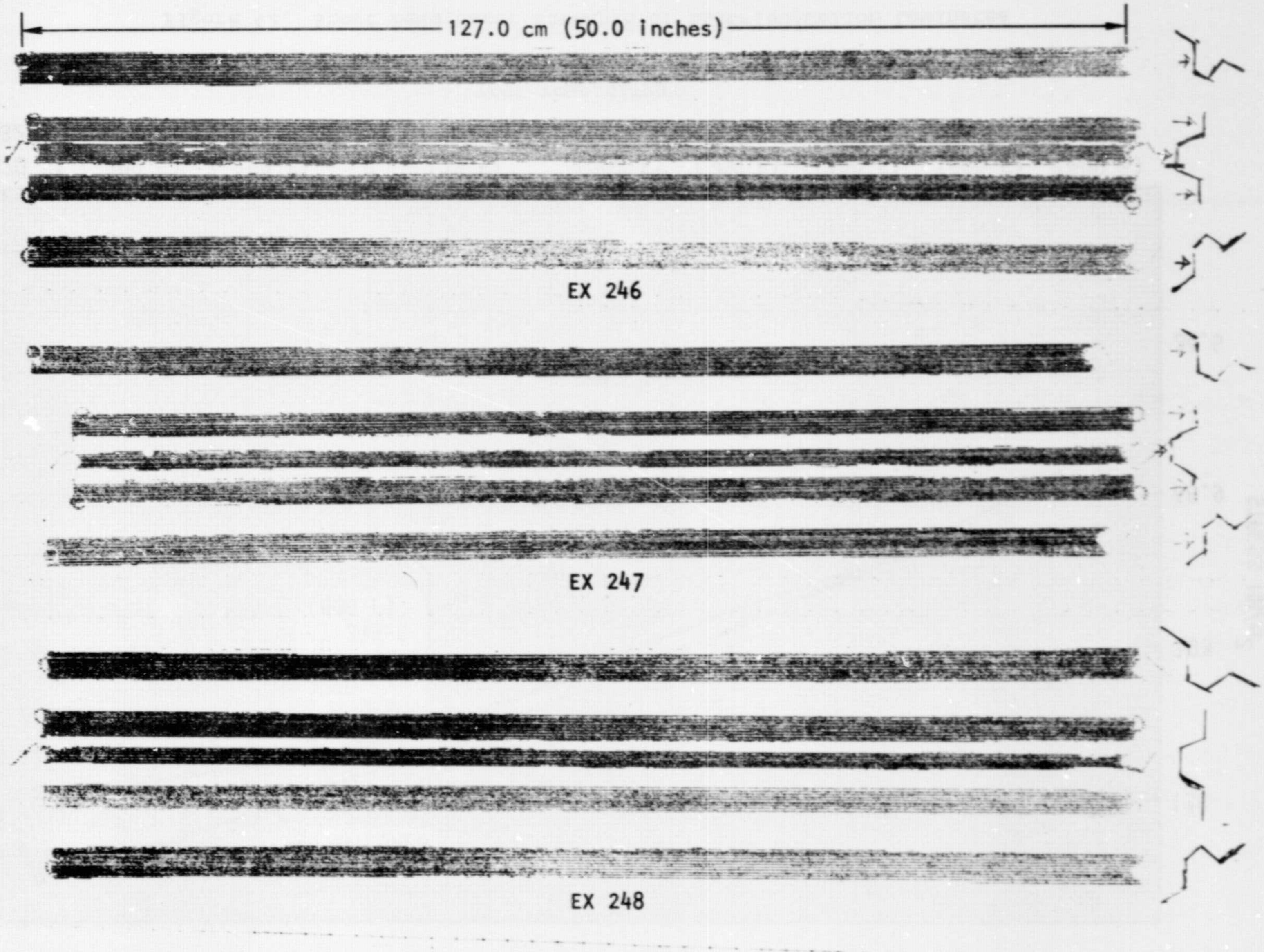


Figure 43. Typical C-Scans of "Hat" Elements

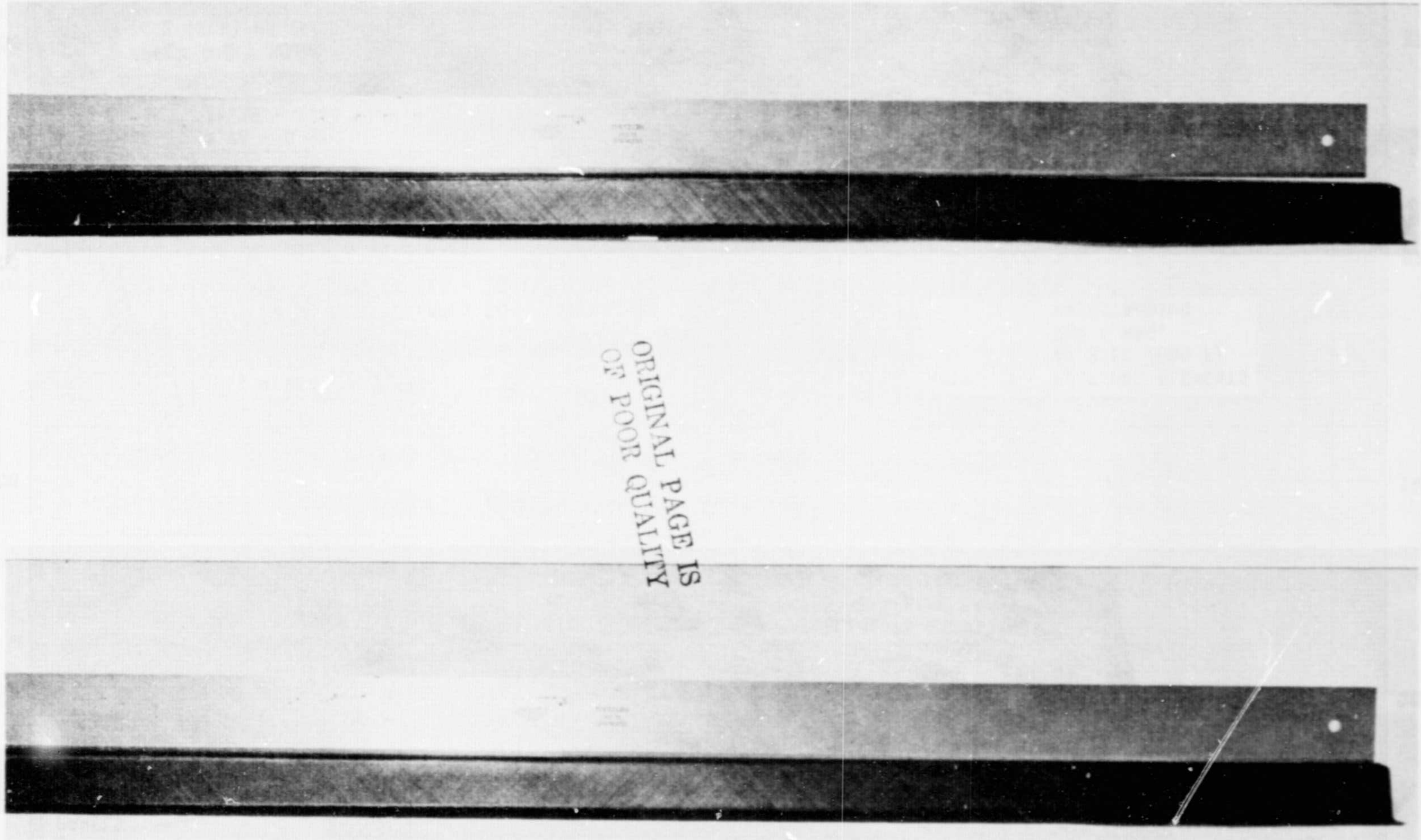


Figure 45. "Hat" Stringer Molded on Reverse Formed Tool—Showing Flat Condition

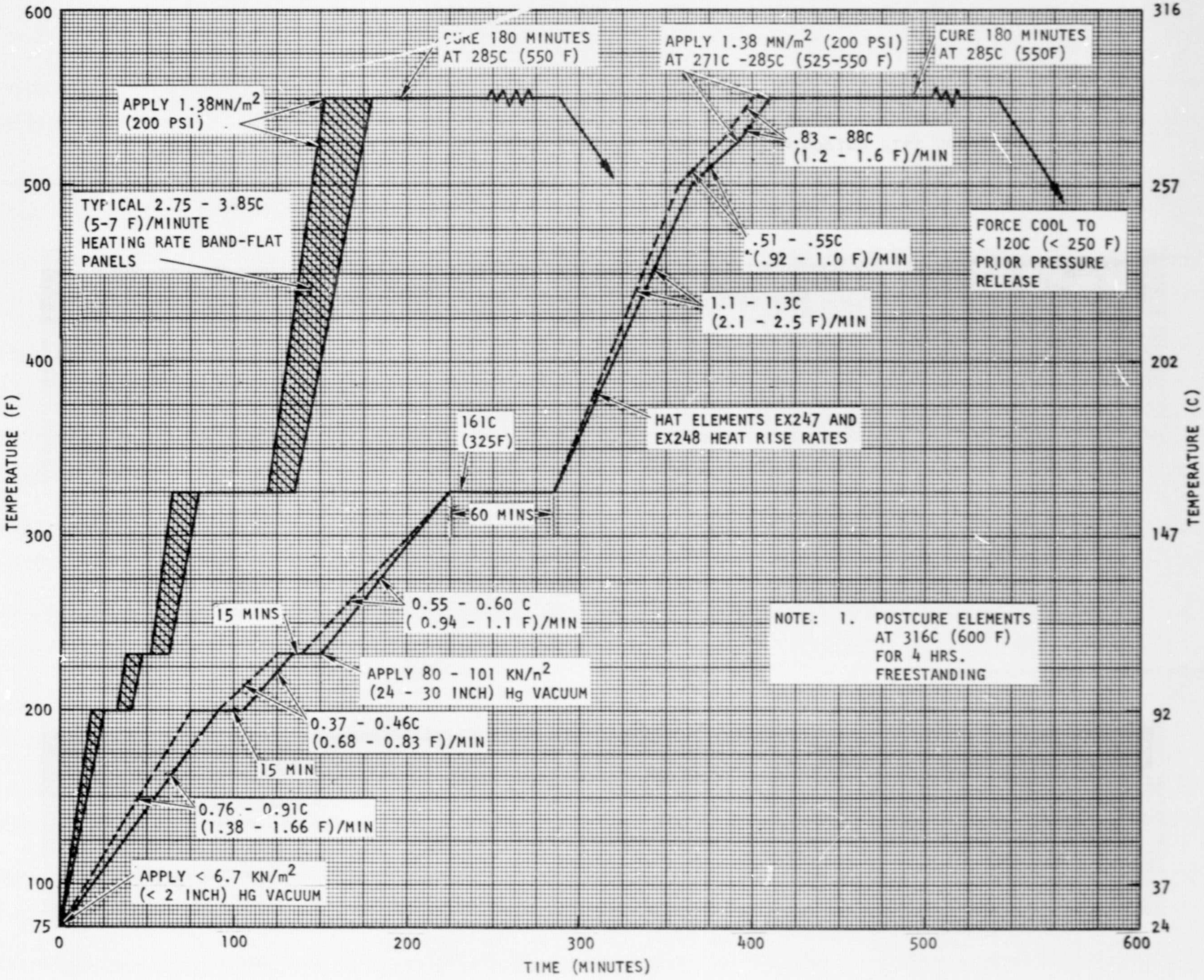


Figure 46. Typical Cure Cycle Events & Heat Rise Rates—Flat Panels and Hat Elements

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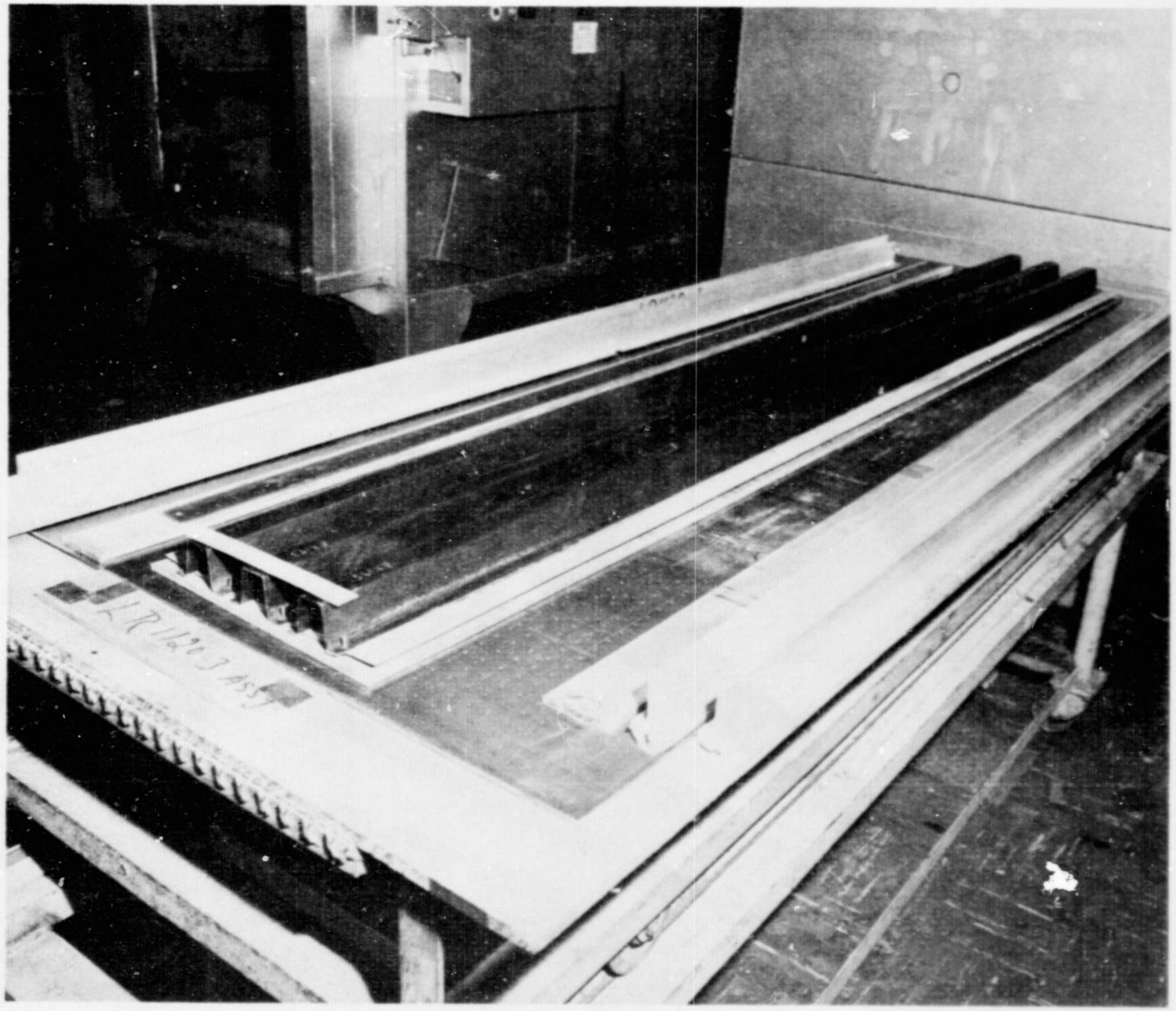


Figure 47. Hat Stringers in Position on Skin—Fit-up Operation

A800122 C-7

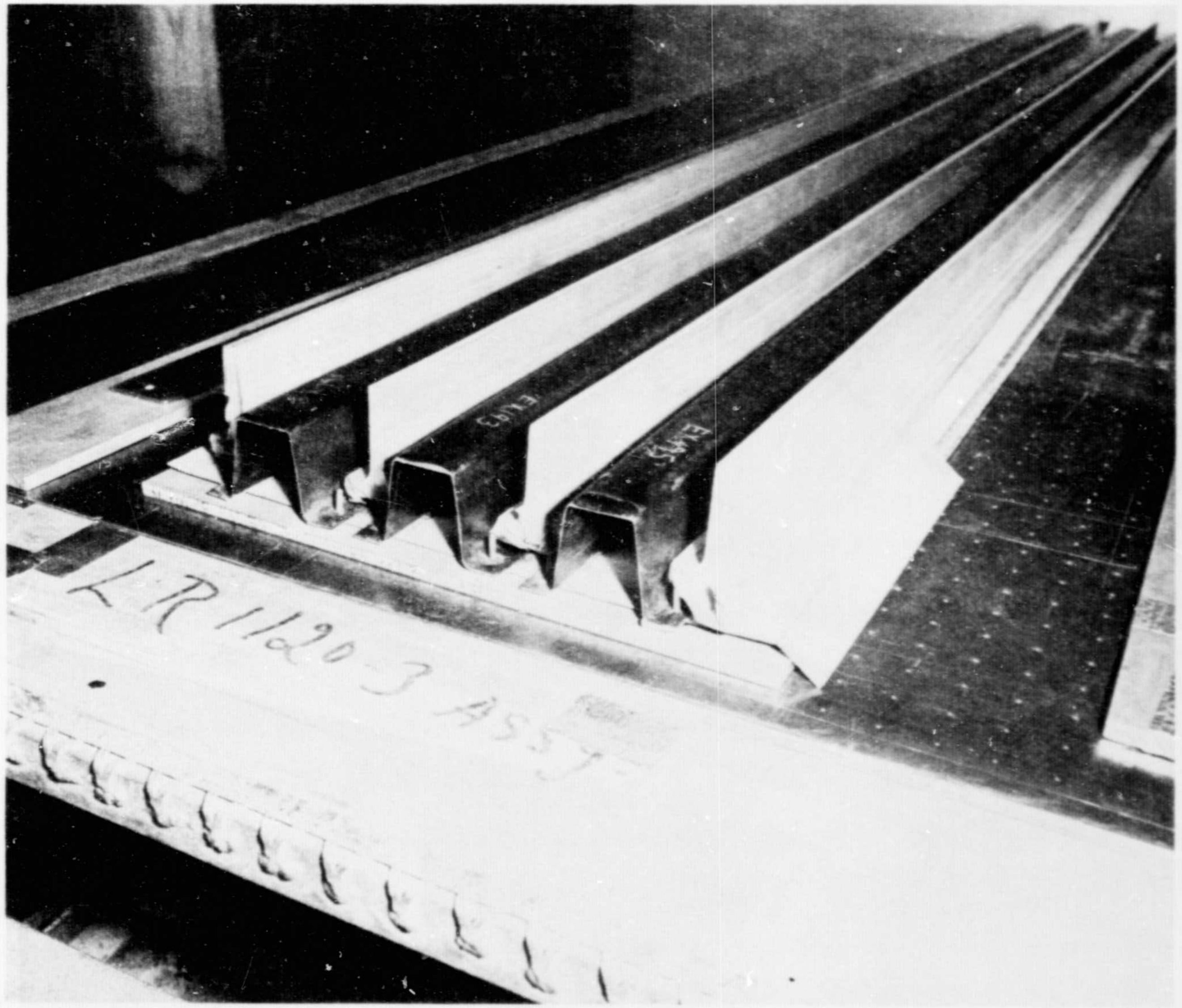


Figure 48. Hat Stringer in Position on Skin With "I" Pressure Cauls Installed

A800122 C-8

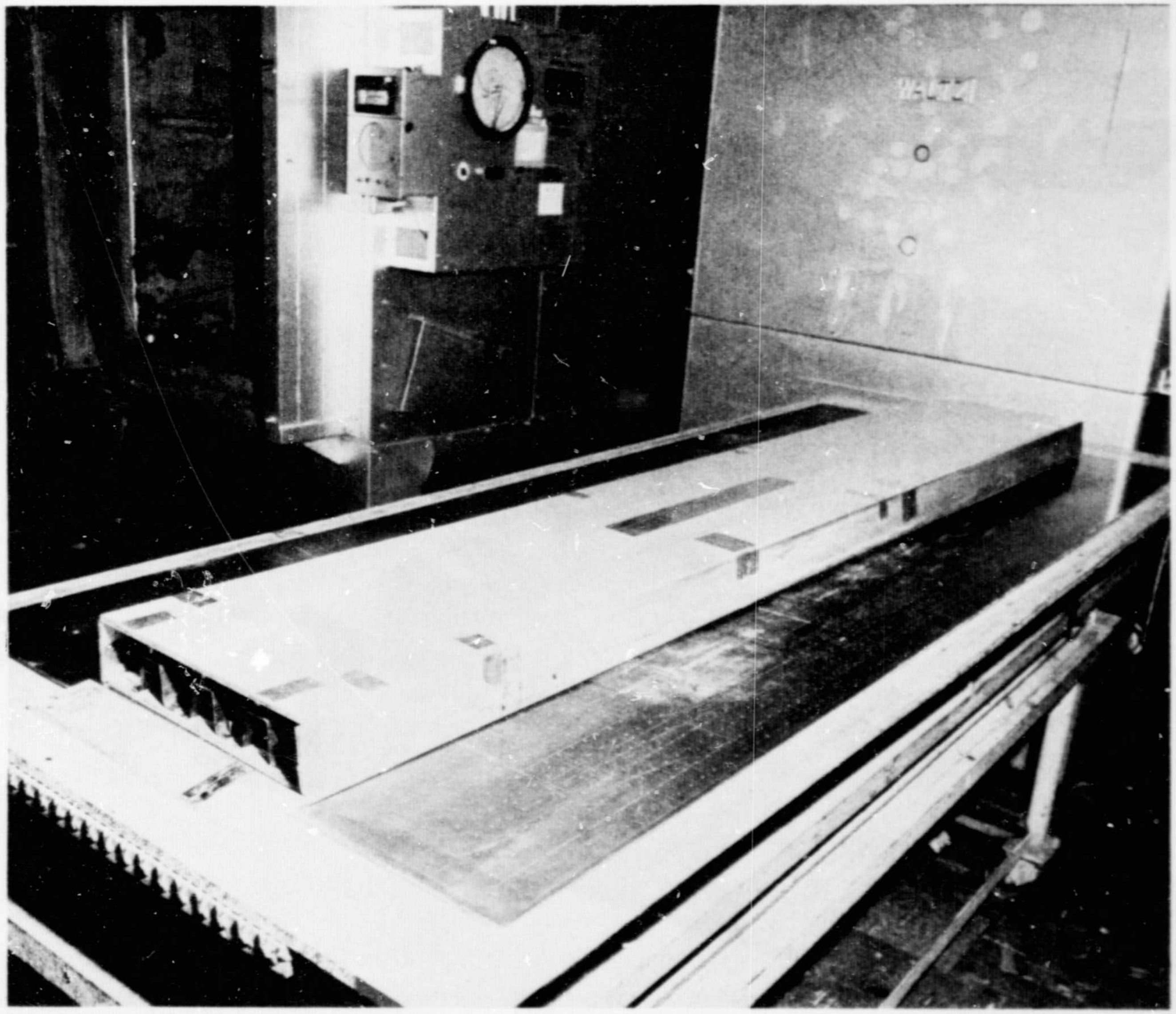
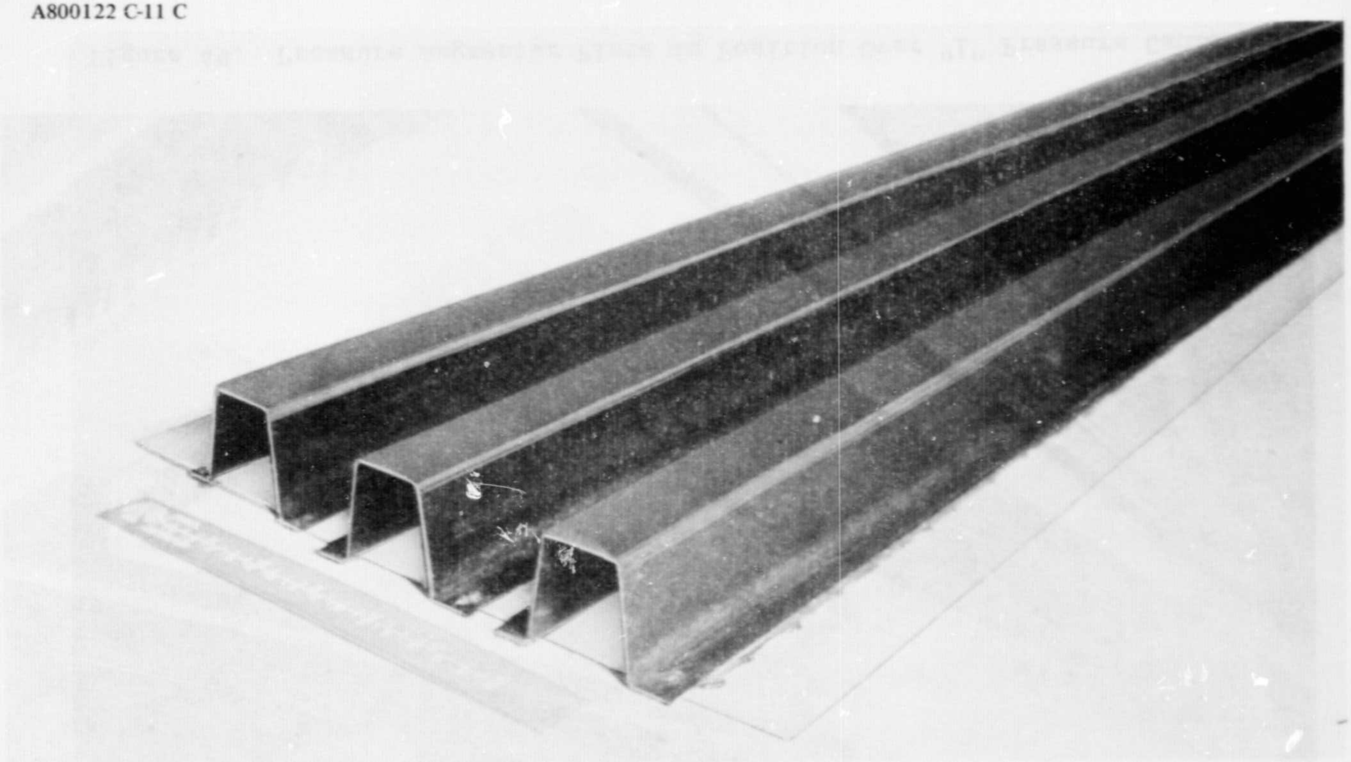


Figure 49. Pressure Augmenter Plate in Position Over "I" Pressure Cauls

A800122 C-11 C



NOTE: PANEL SIZE
29.8 X 193.0 CM
(11.75 X 76 INCHES)

A800122 C-10 C

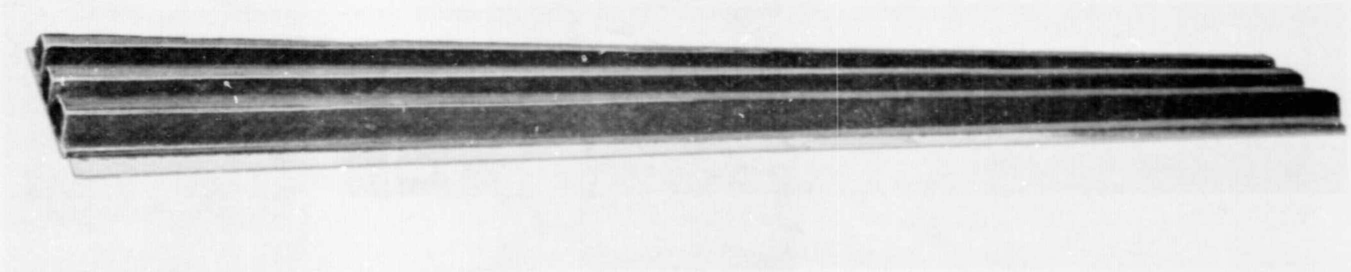


Figure 50. "Hat" Stiffened Skin/Stringer—Bonding Complete

A800122 C-12

Figure 51. "Hat" Stiffened Skin/Stringer Showing Concave Skin Surface

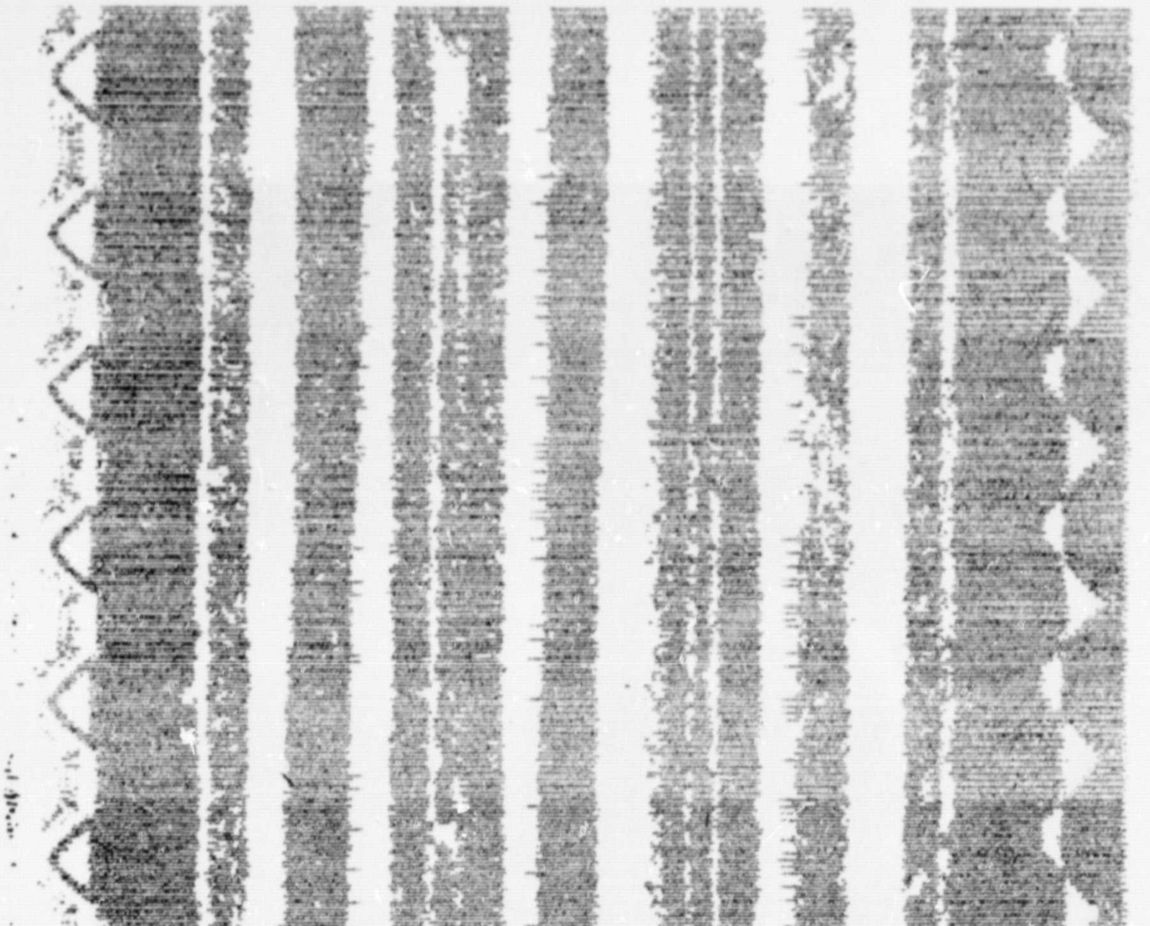
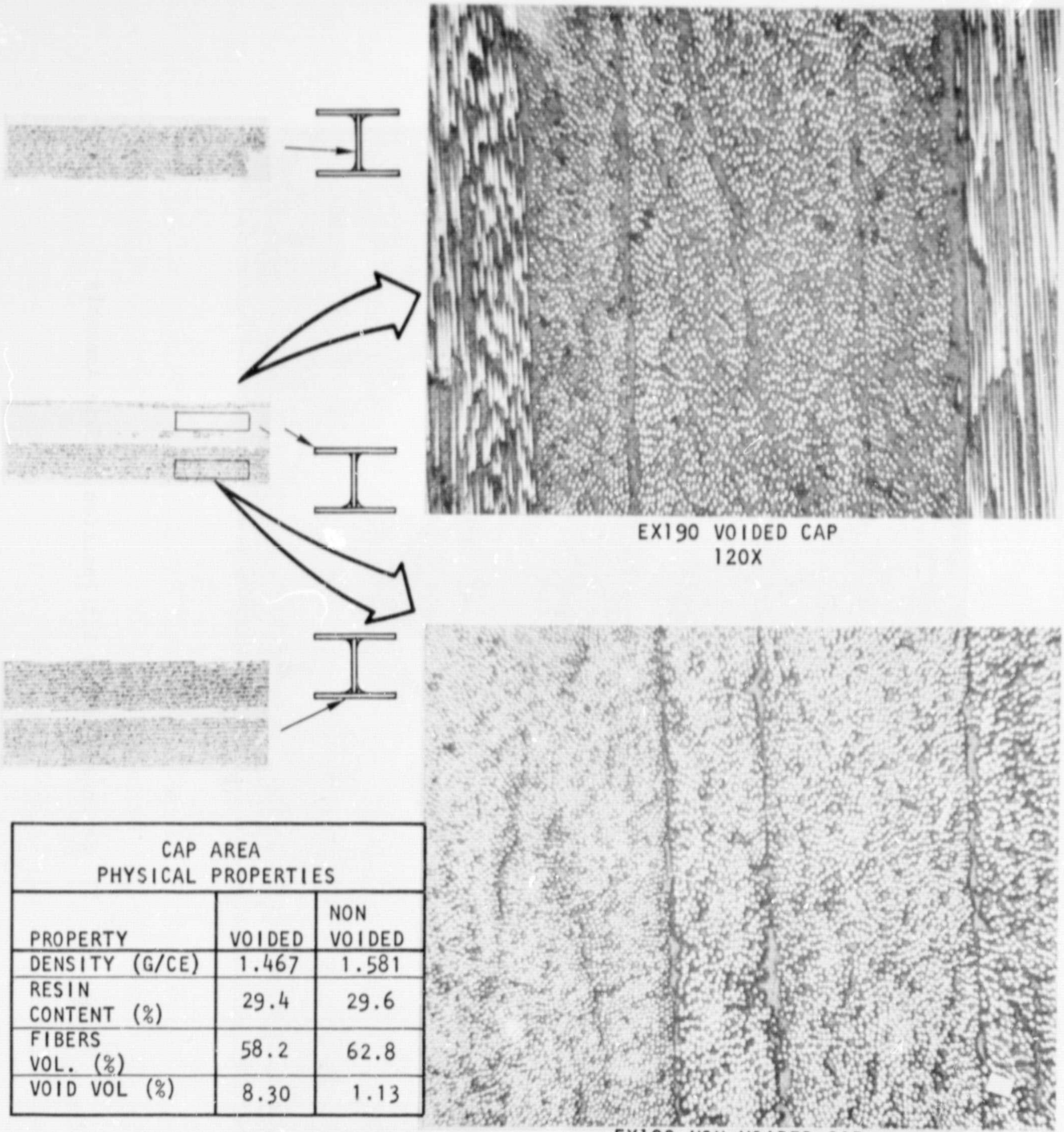


Figure 52. C-Scan of Hat-to-Skin Bond, Typical Area - 1/2 Scale



CAP AREA PHYSICAL PROPERTIES		
PROPERTY	VOIDED	NON VOIDED
DENSITY (G/CE)	1.467	1.581
RESIN CONTENT (%)	29.4	29.6
FIBERS VOL. (%)	58.2	62.8
VOID VOL (%)	8.30	1.13

Figure 53. C-Scan and Photomicrograph Correlation of "I" Stringer Cap Void Characteristics

A800122 C-2

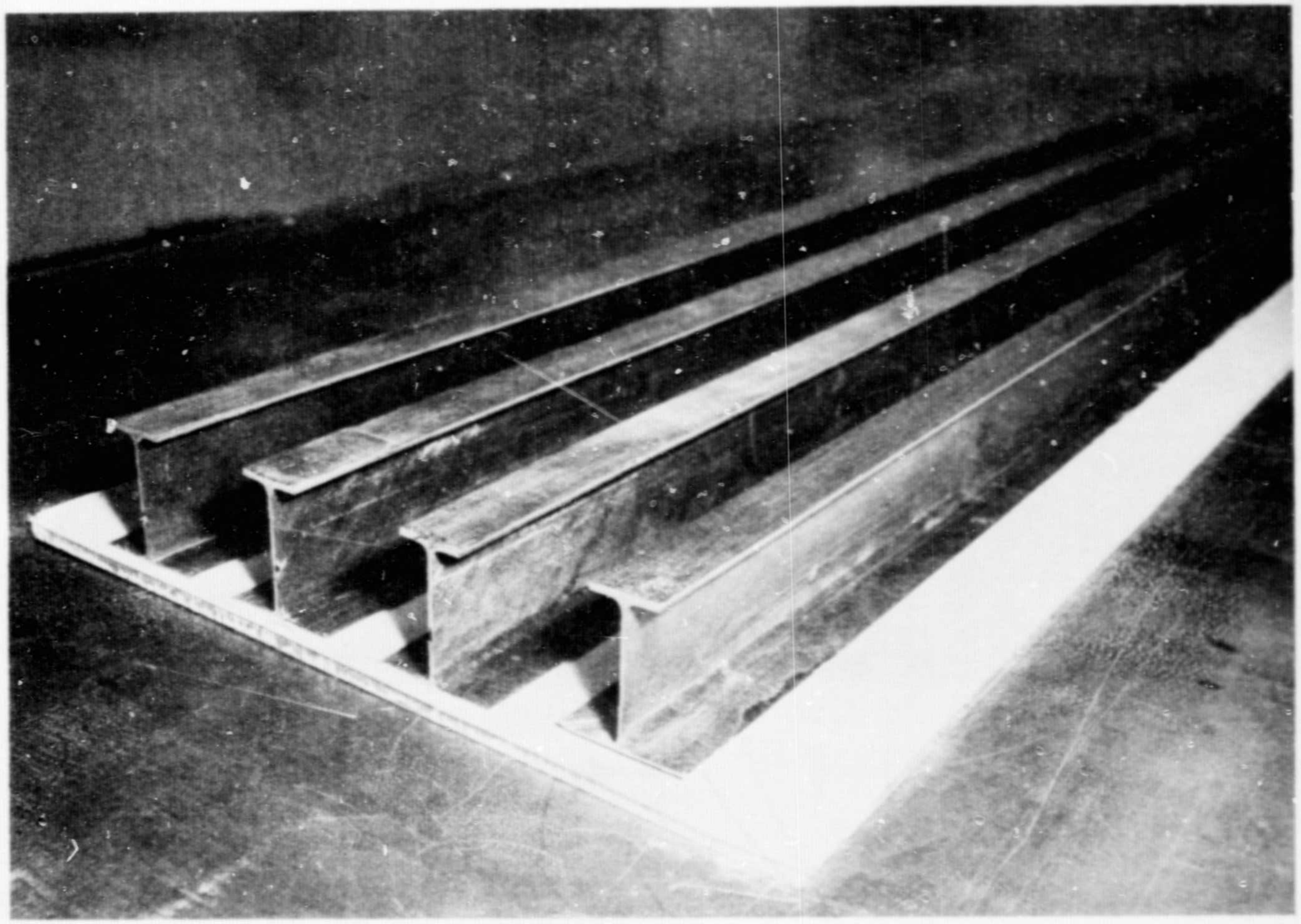


Figure 54. "I" Stringers in Dry Fit Position on Skin Assembly

A800122 C-3

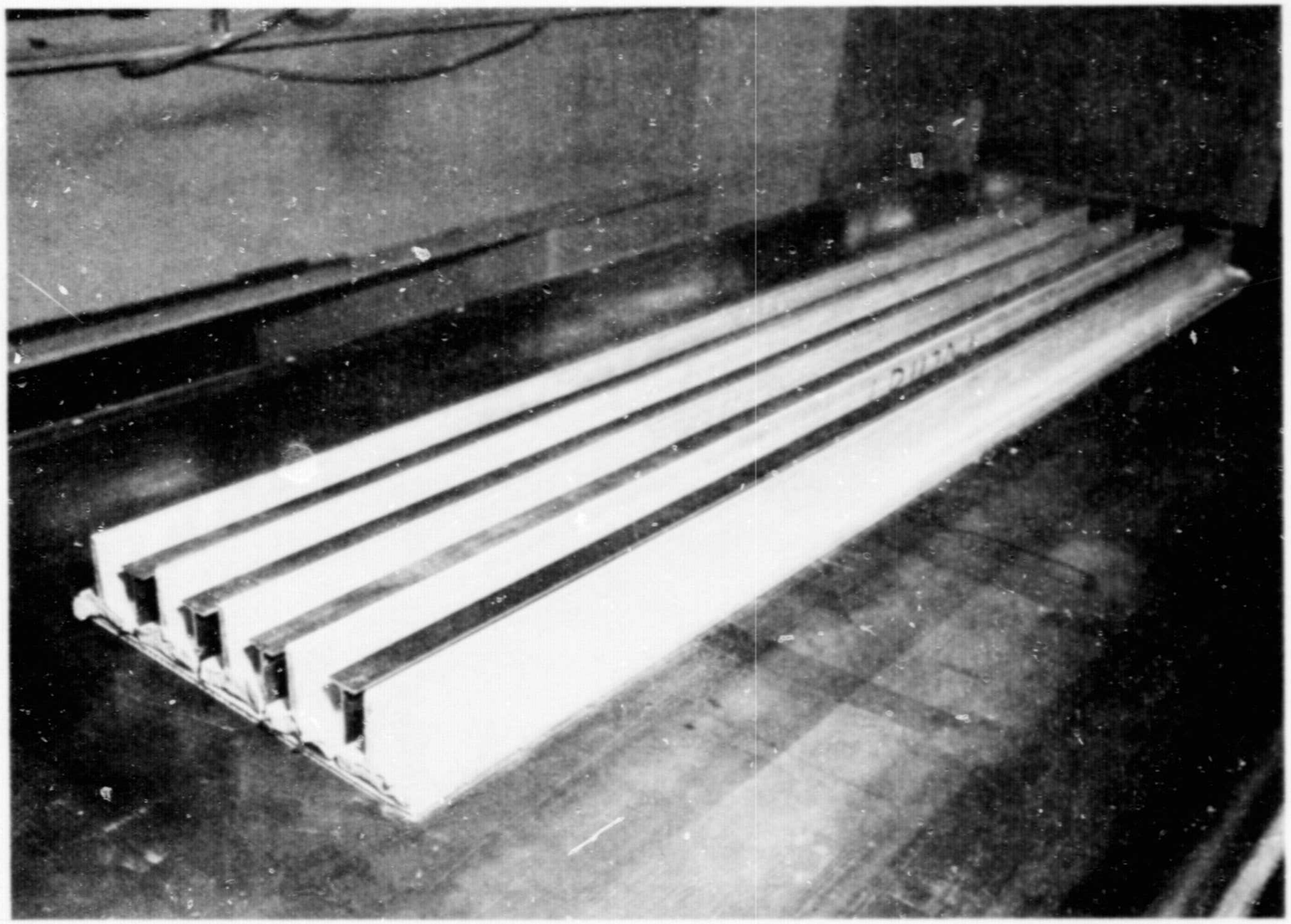


Figure 55. "I" Stringer in Bonding Position With "I" Pressure Cauls Installed

A800122 C-4

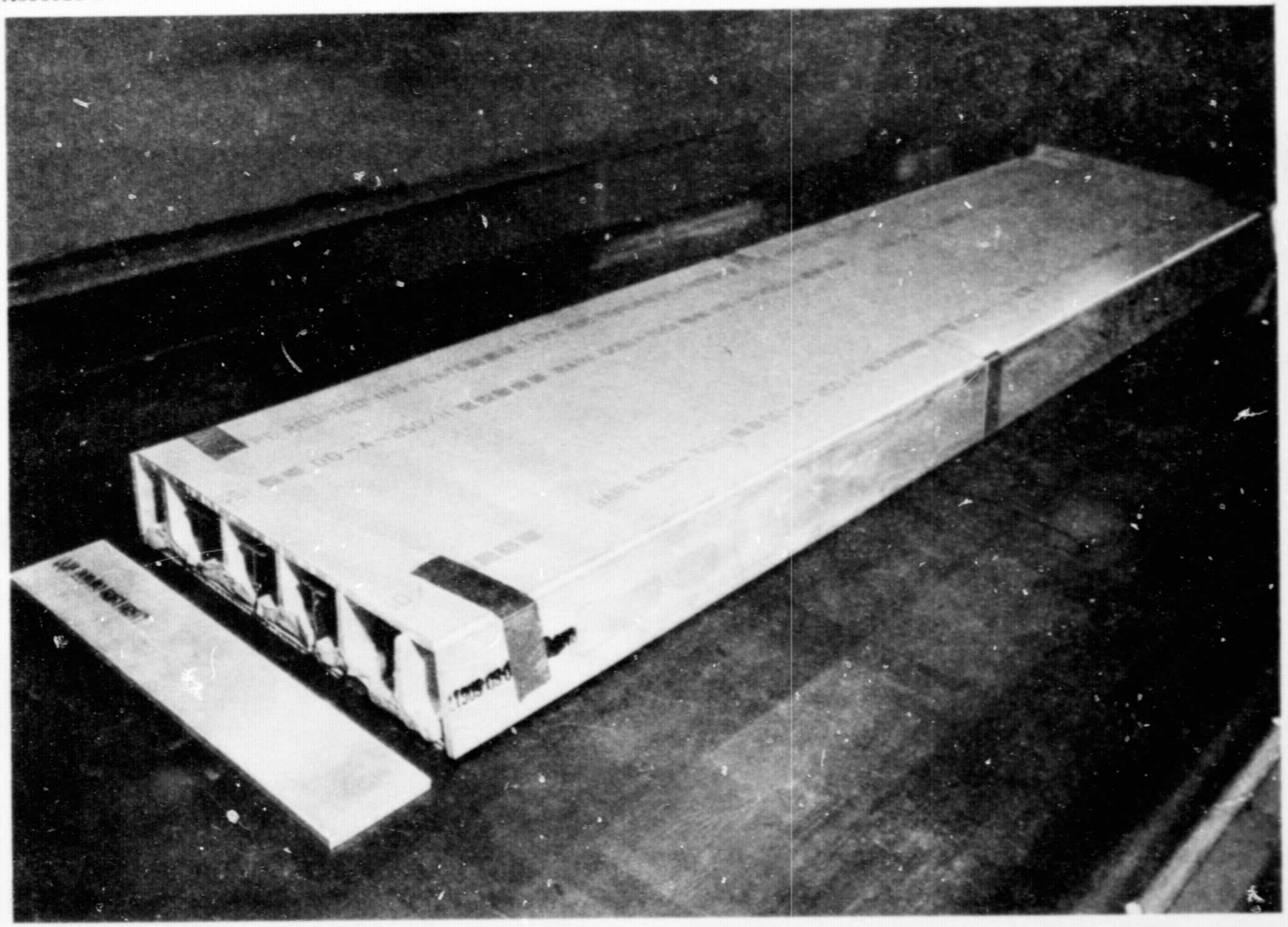


Figure 56. Pressure Augmenter Plate in Position Over "⊥" Pressure Cauls, "I" Stiffened Skin/Stringer Assembly

A800122 C-5

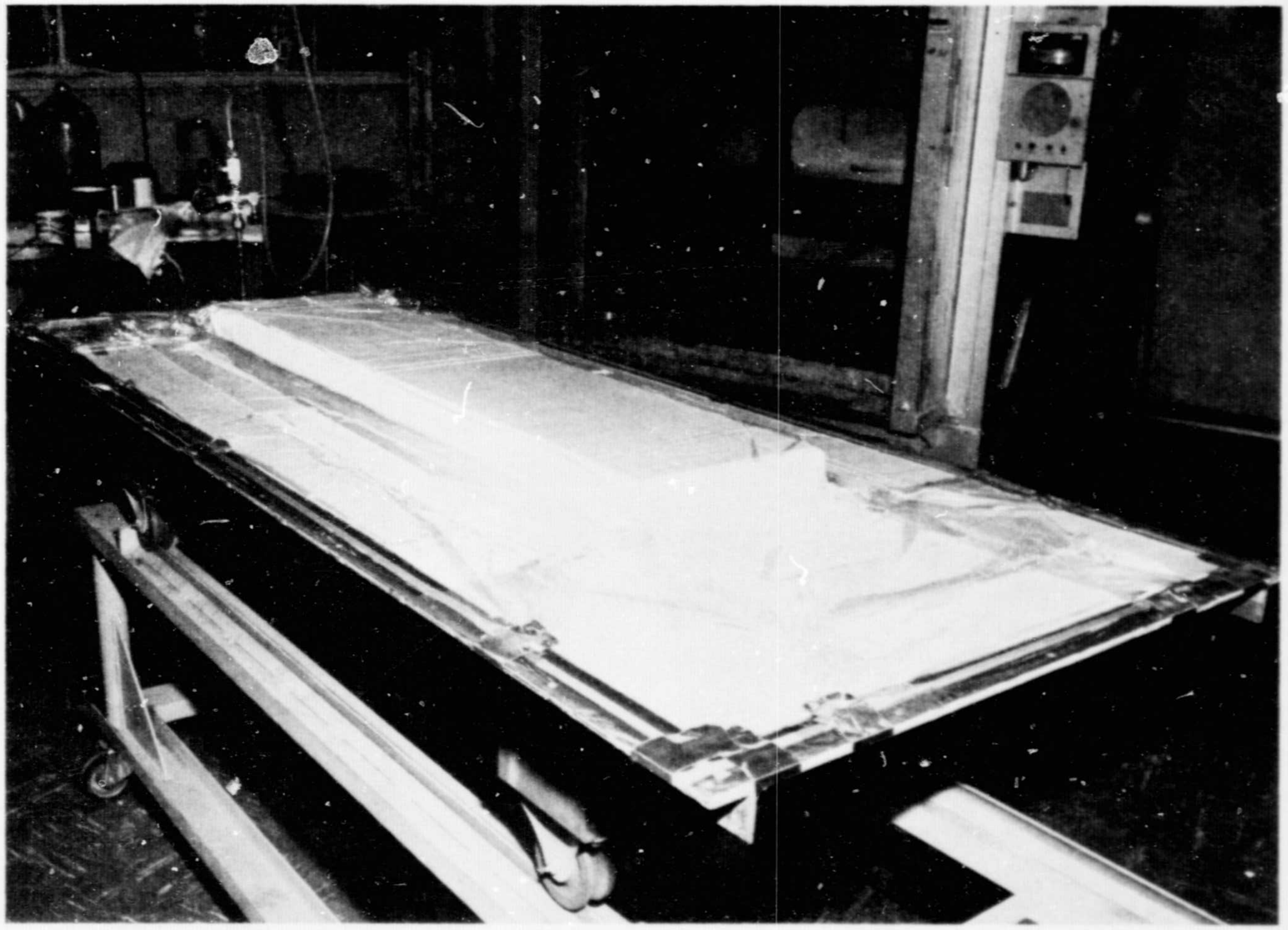
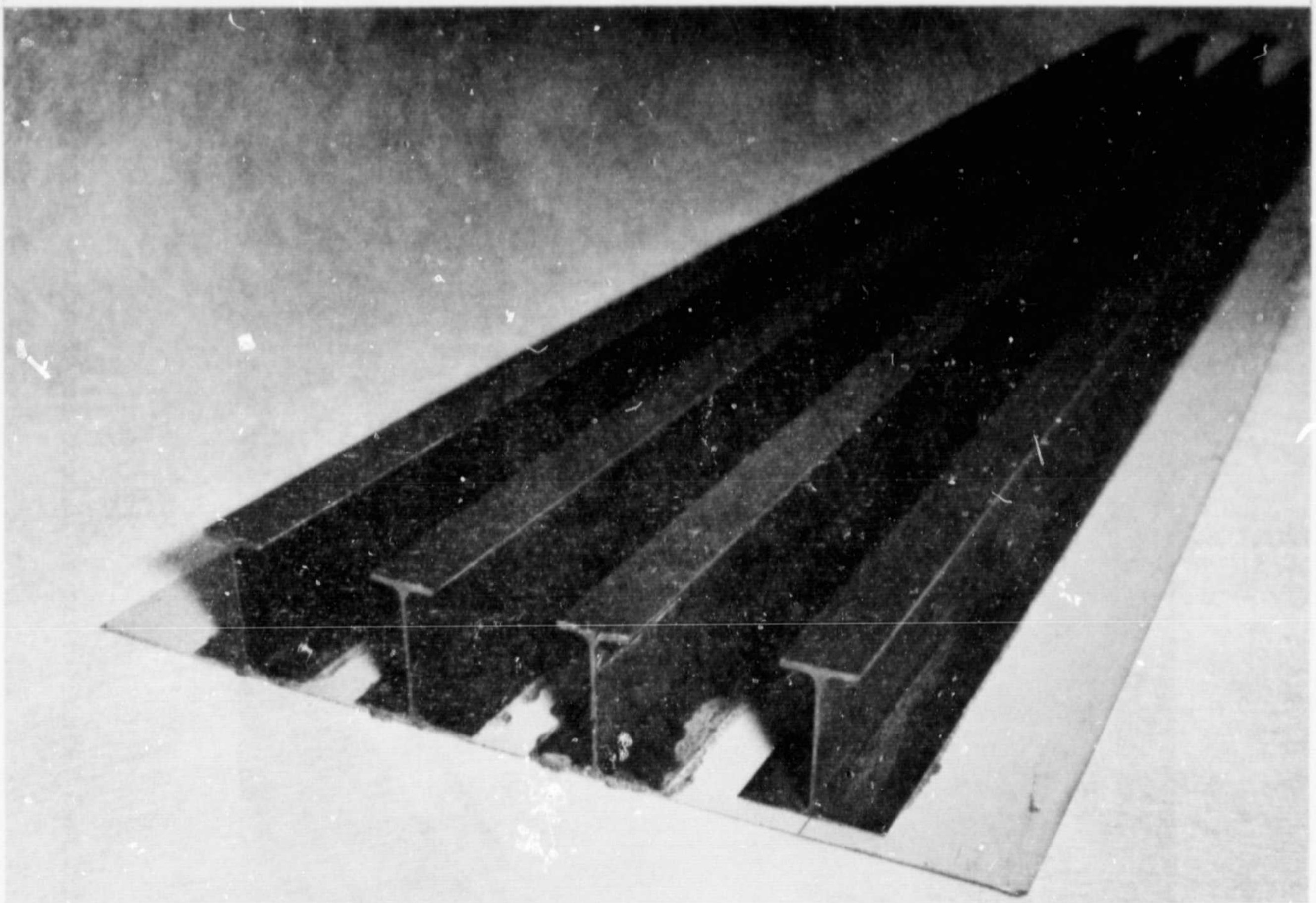


Figure 57. "I" Stringer Stiffened Skin Element in Vacuum Bag Bonding Fixture

A800125 C-2



A800125 C-1

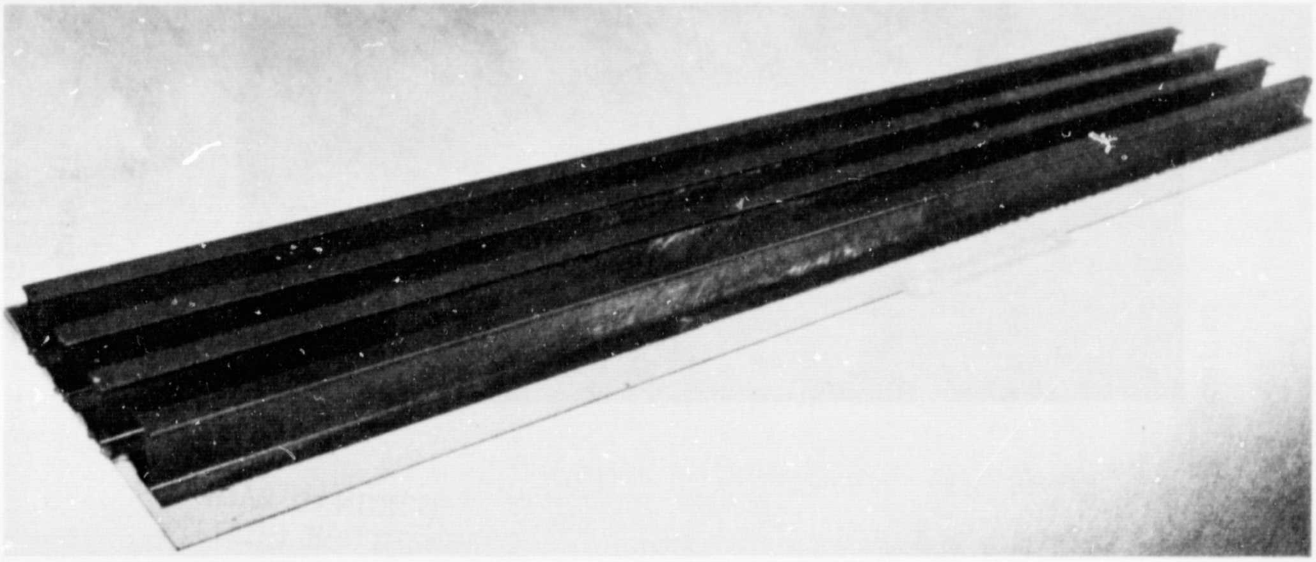


Figure 58. "I" Stiffened Skin/Stringer Panel Bonded Complete

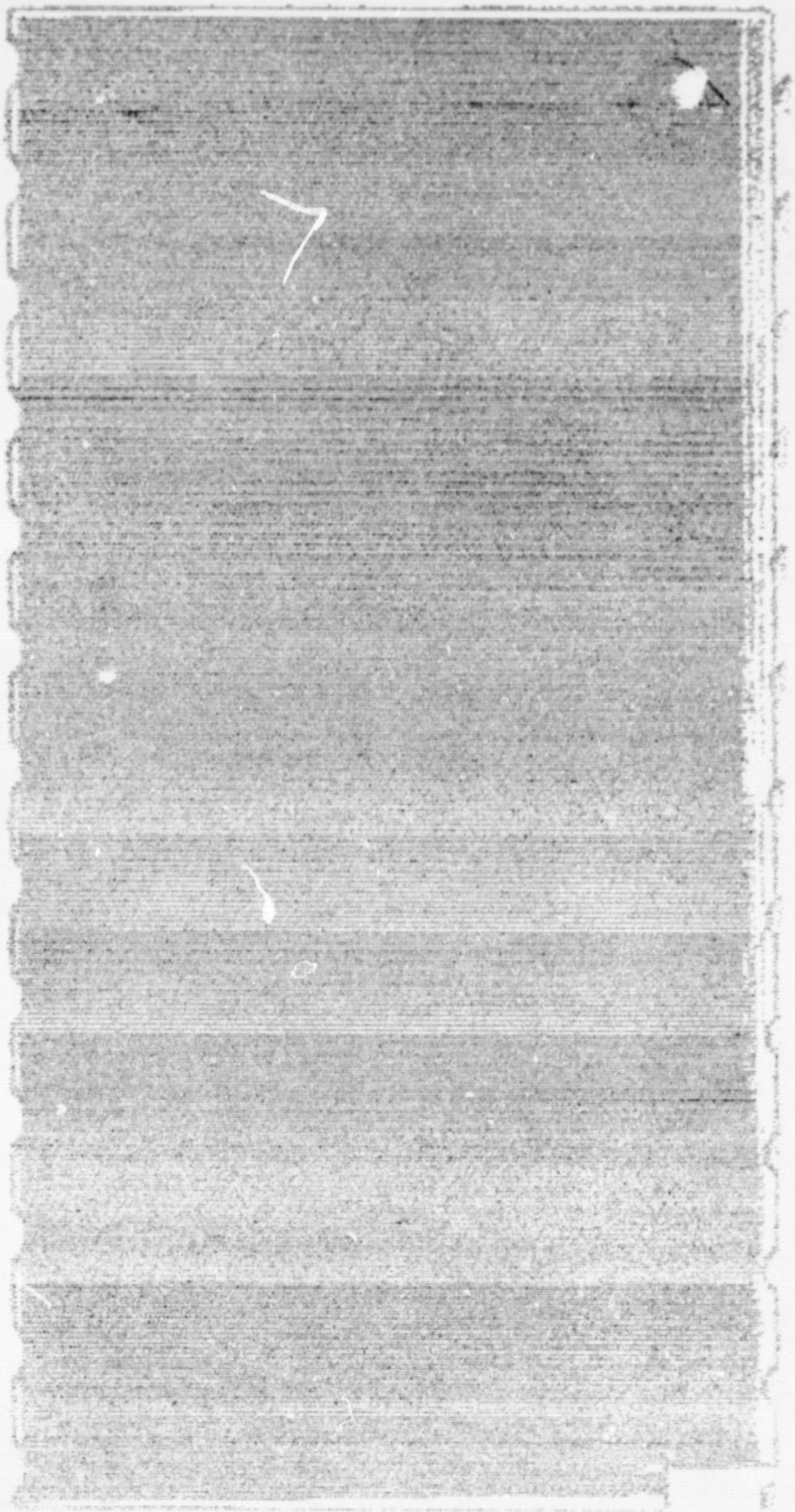


Figure 59. C-Scan of 35X34 5 Harness Satin Weave Celion Fabric/
LARC-160 Laminate 0.33 cm Thick

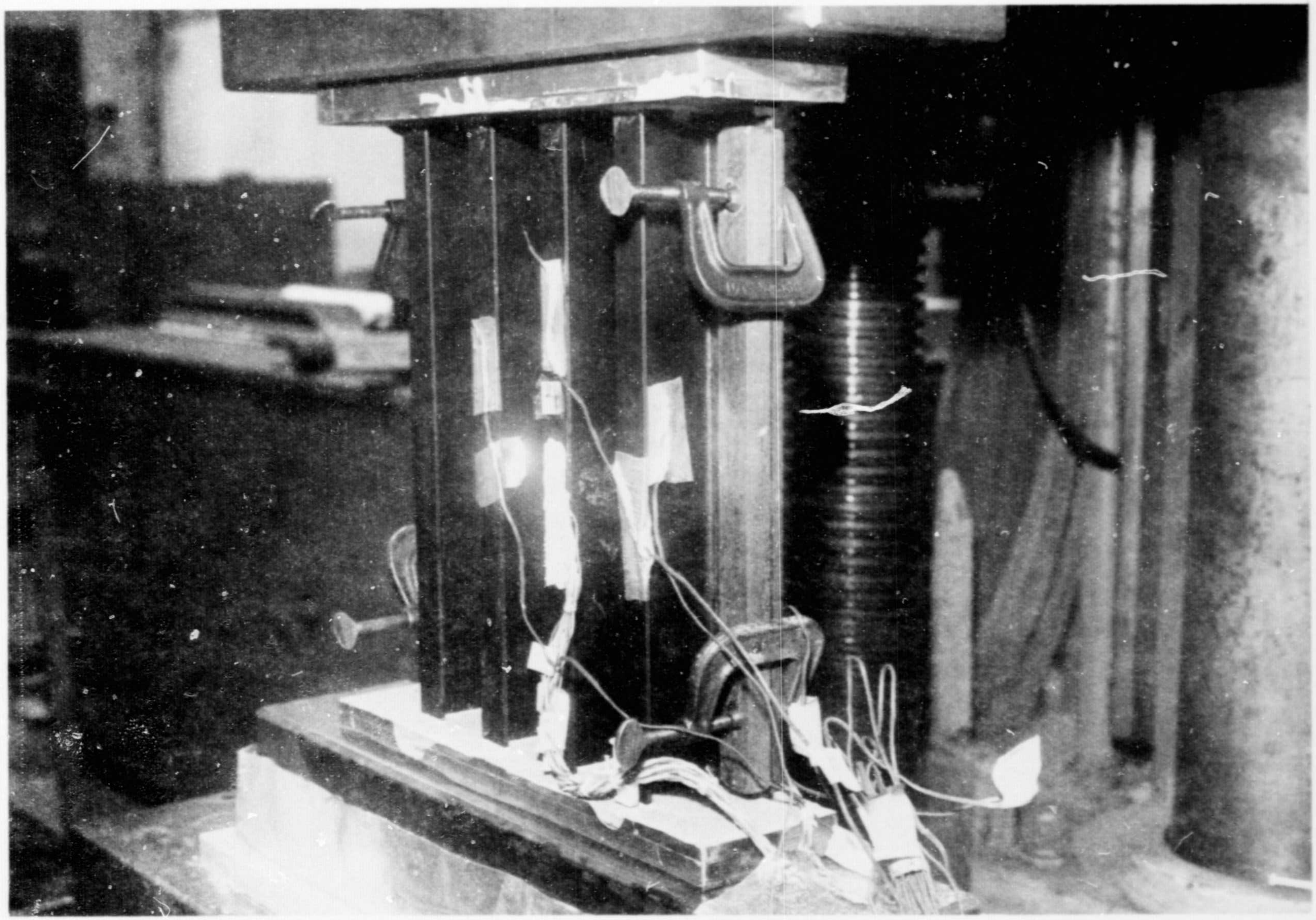


Figure 60. "I" Stringer Stiffened Skin Panel Element EX111/EX113 Being Readied for -132 C (-270 F) Test

ORIGINAL PAGE IS
OF POOR QUALITY

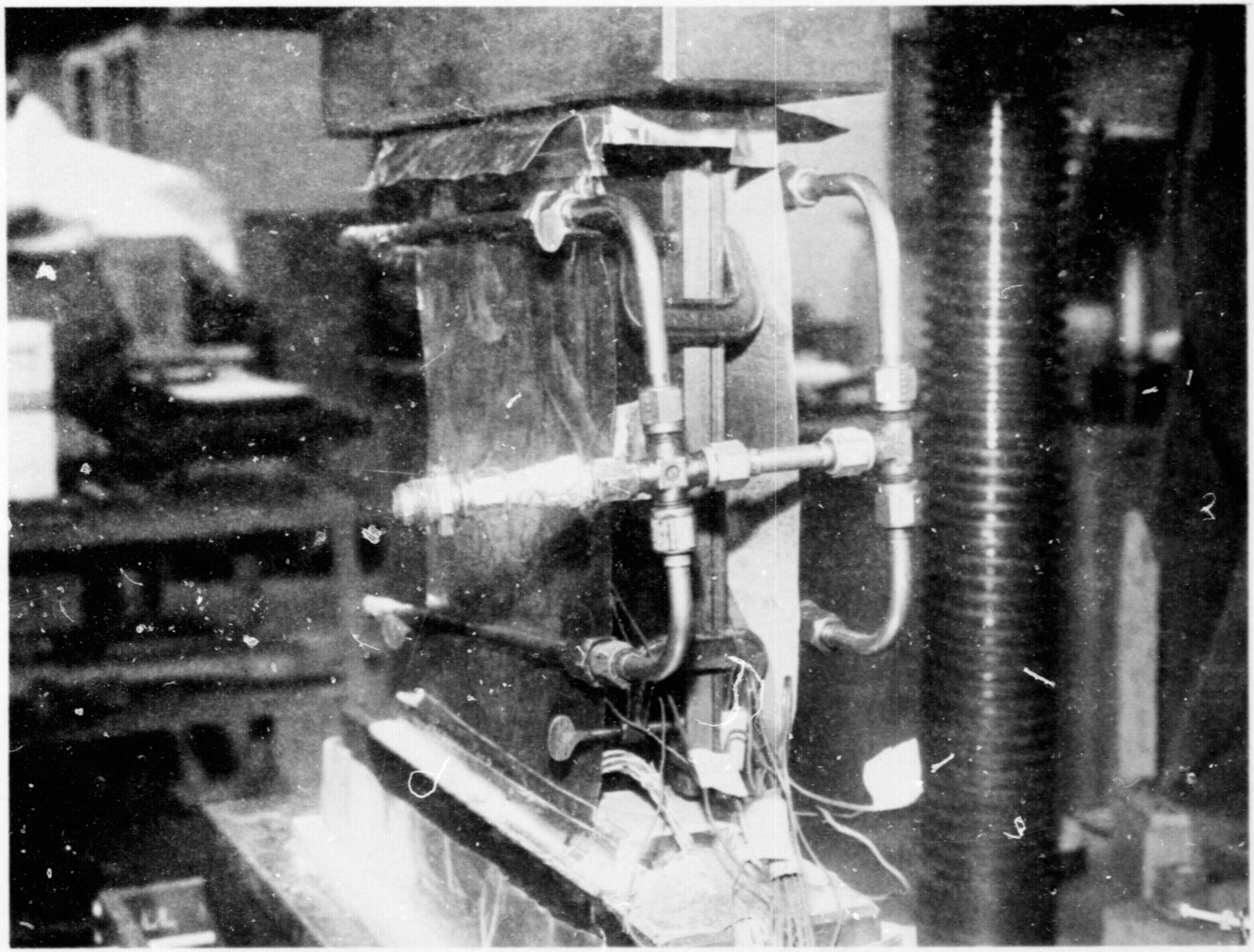


Figure 61. "I" Stiffened Skin/Stringer Panel, LN_2 Manifolds and Baffle Plates in Place

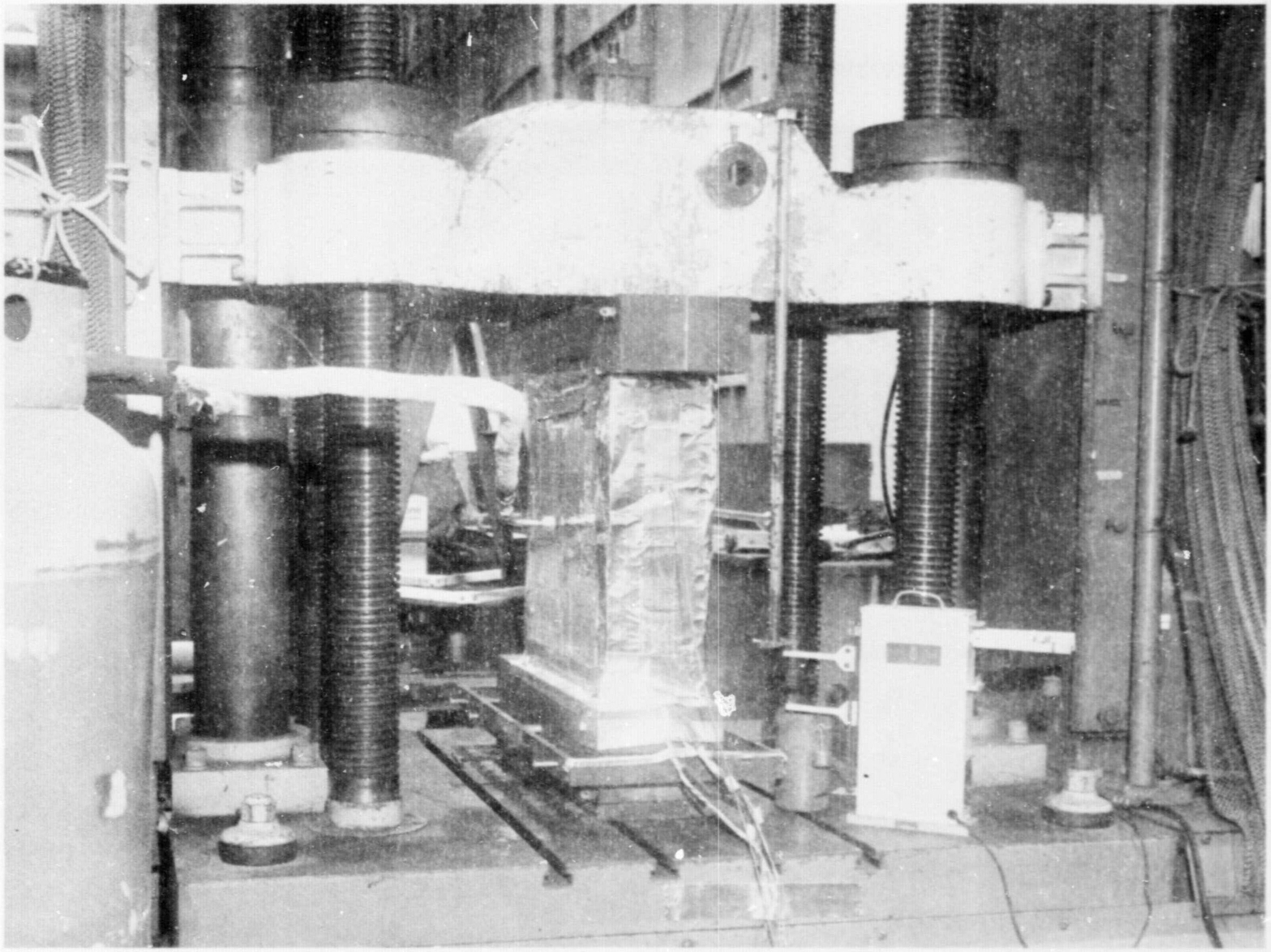


Figure 62. Typical Test Set-up for -132 C (-270 F) Compression Element Test

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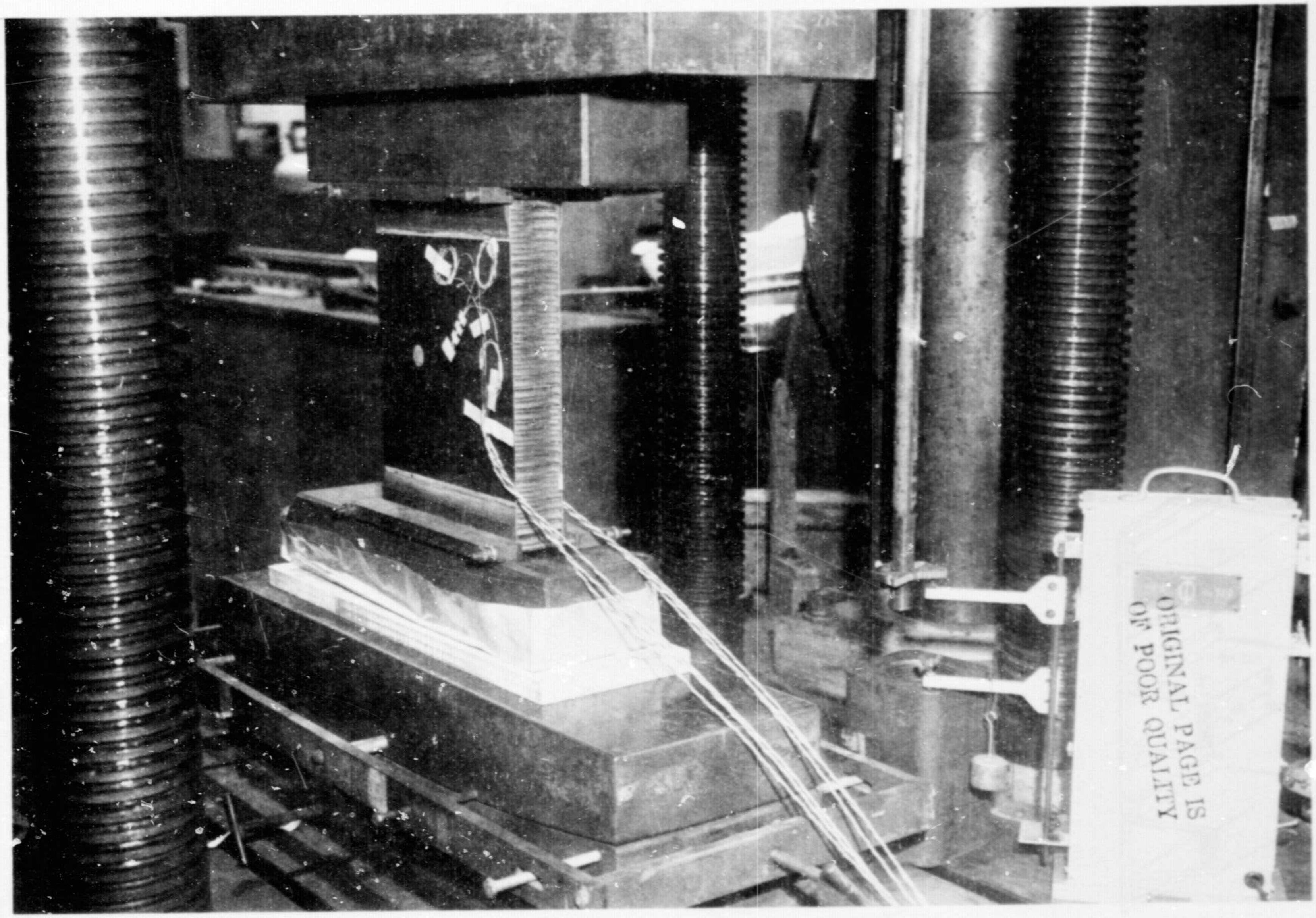


Figure 63. Sandwich Element R.T. Test Set-up

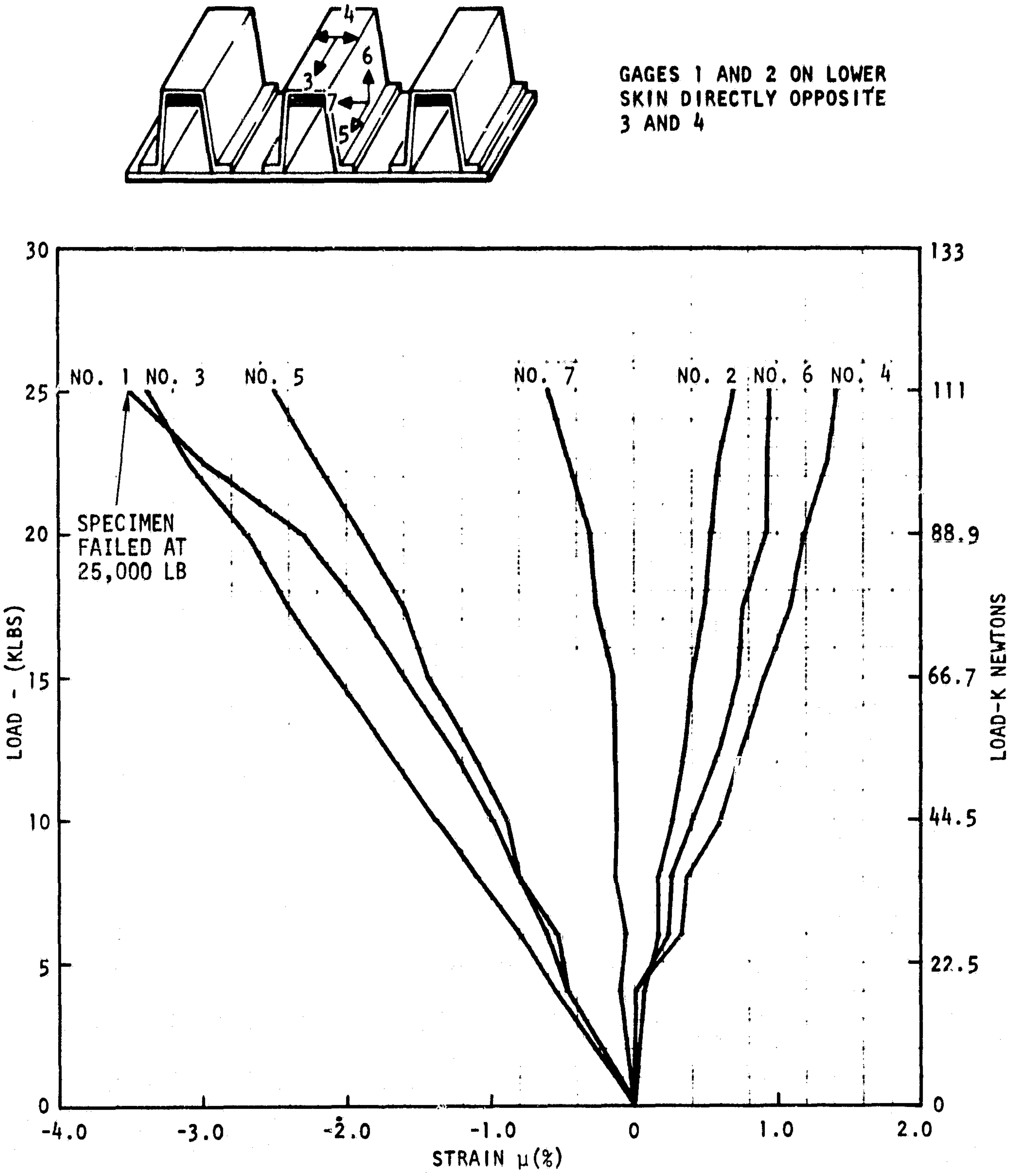
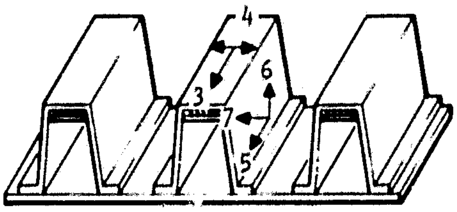


Figure 64. Load/Strain Characteristics of "Hat" Stringer Stiffened Skin Element EX109/EX110 AT-132C (-270F)



GAGES 1 AND 2 ON LOWER SKIN DIRECTLY OPPOSITE 3 AND 4

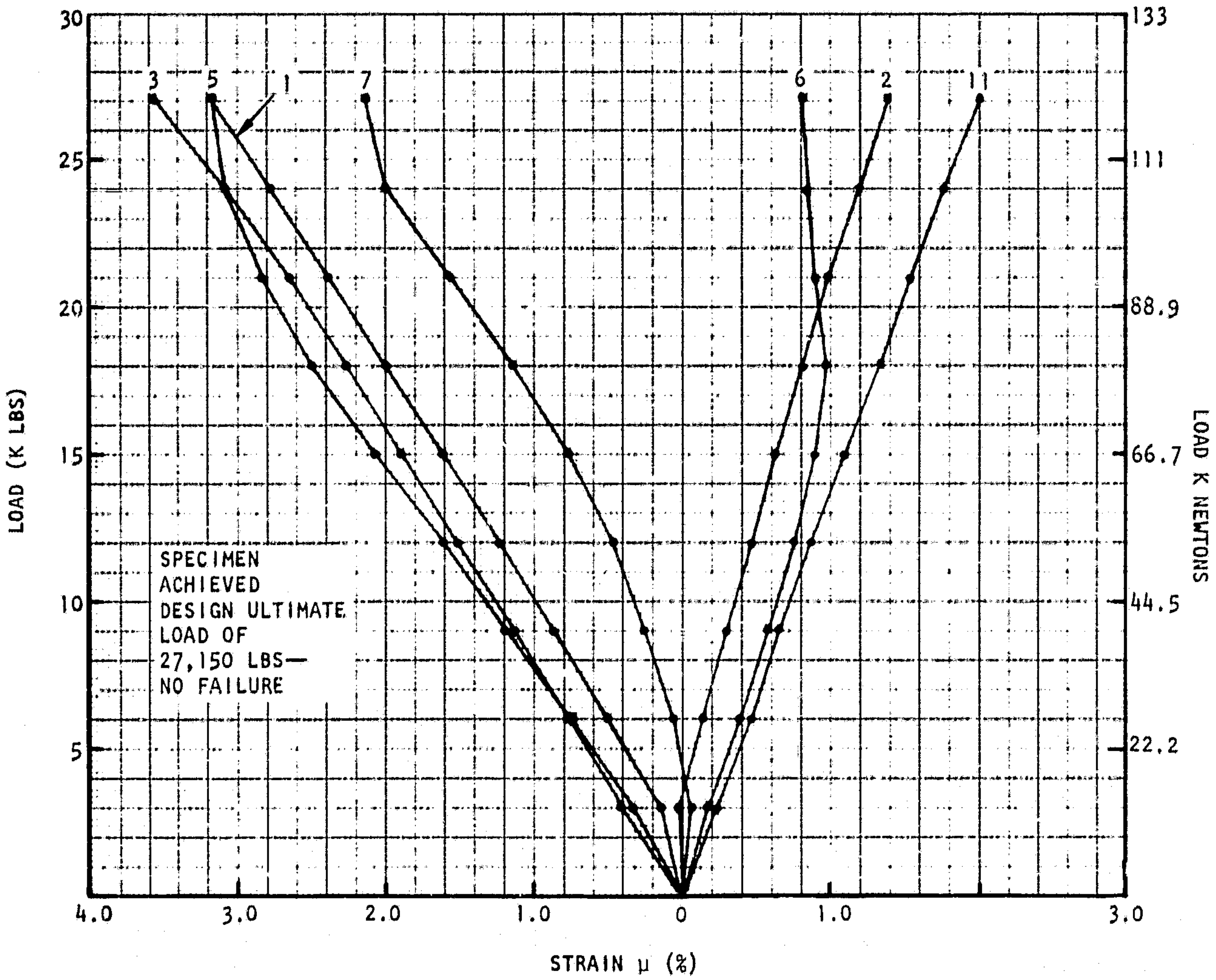
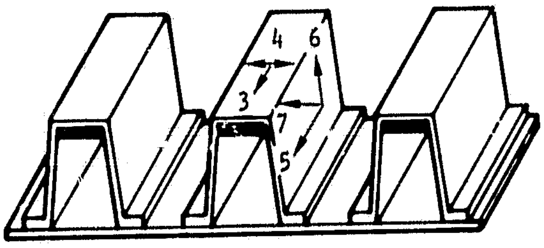


Figure 65. Compression Load/Strain Characteristics of "Hat" Stringer Stiffened Skin Element EX195-4A Aged 125 Hours at 316 C (600 F) and Tested at—132 C (-270 F)



STRAIN GAGES 1 AND 2 ON LOWER SKIN DIRECTLY OPPOSITE 3 AND 4

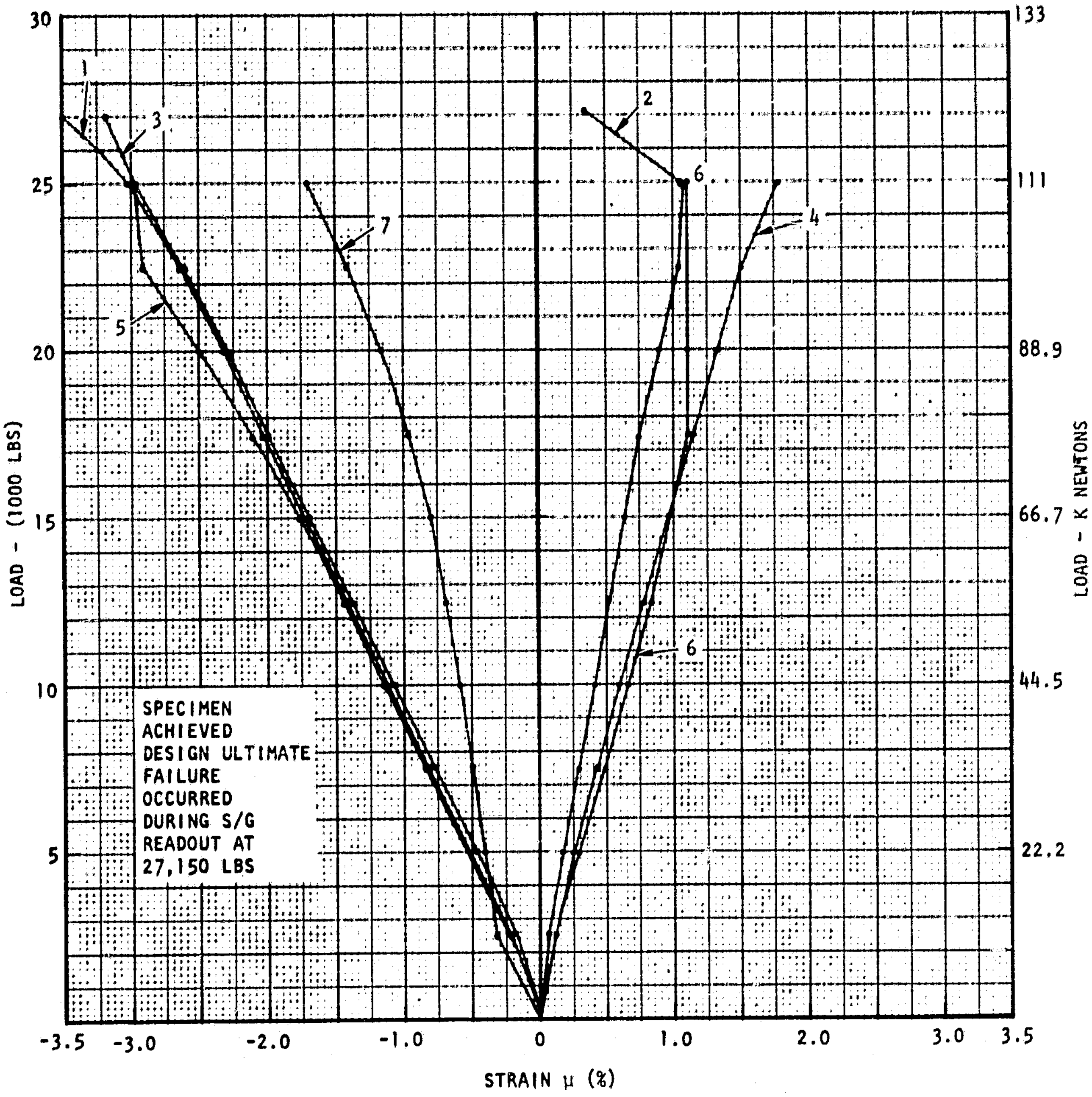
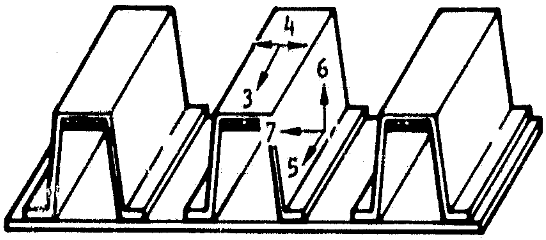


Figure 66. Compression Load/Strain Characteristics of Hat Stringer Stiffened Skin Element E109/EX110A, Postcured Condition Tested at Room Temperature



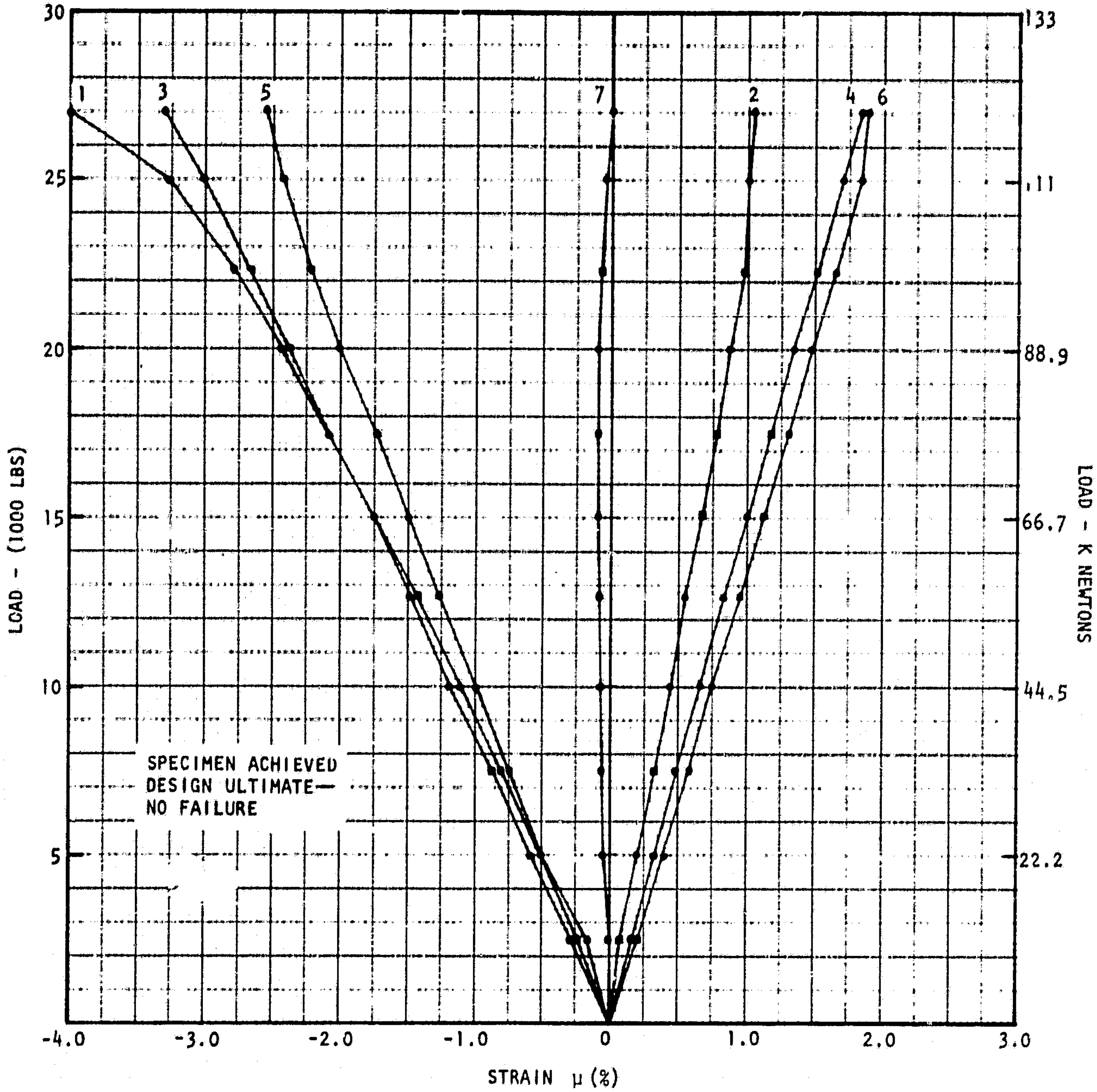


Figure 67. Compression Load/Strain Characteristics of Hat Stringer Stiffened Skin Element EX109/EX110B, Postcured Condition Tested at Room Temperature

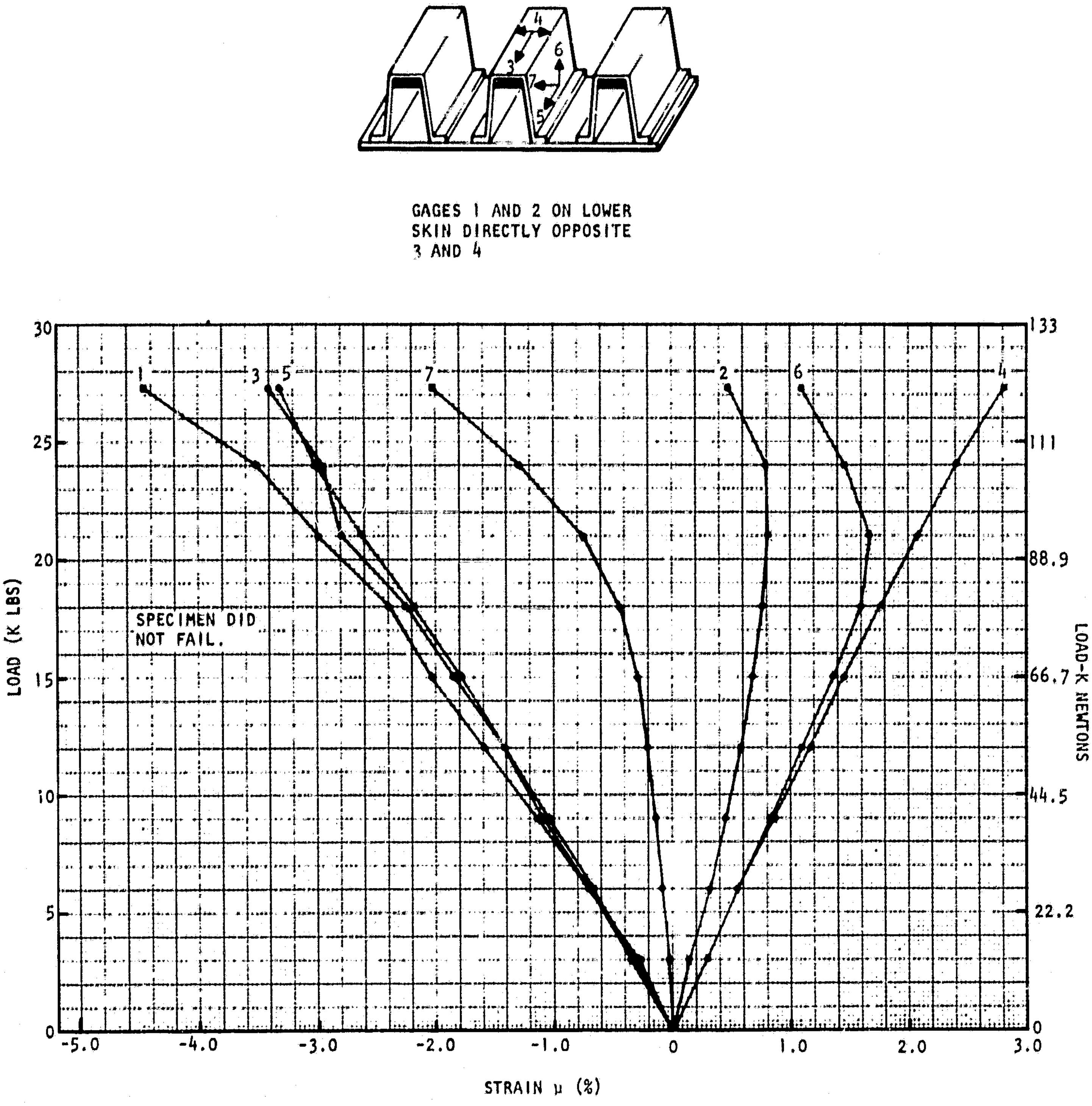
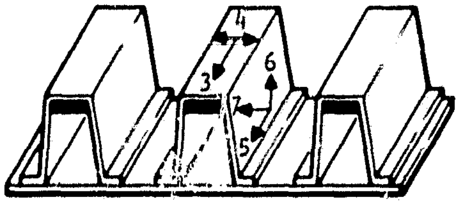


Figure 68. Load/Strain Characteristics of "Hat" Stringer Stiffened Skin Element EX195-2A Aged 125 Hours at 316 C (600 F) Tested at Room Temperature



GAGES 1 AND 2 ON LOWER SKIN DIRECTLY OPPOSITE 3 AND 4

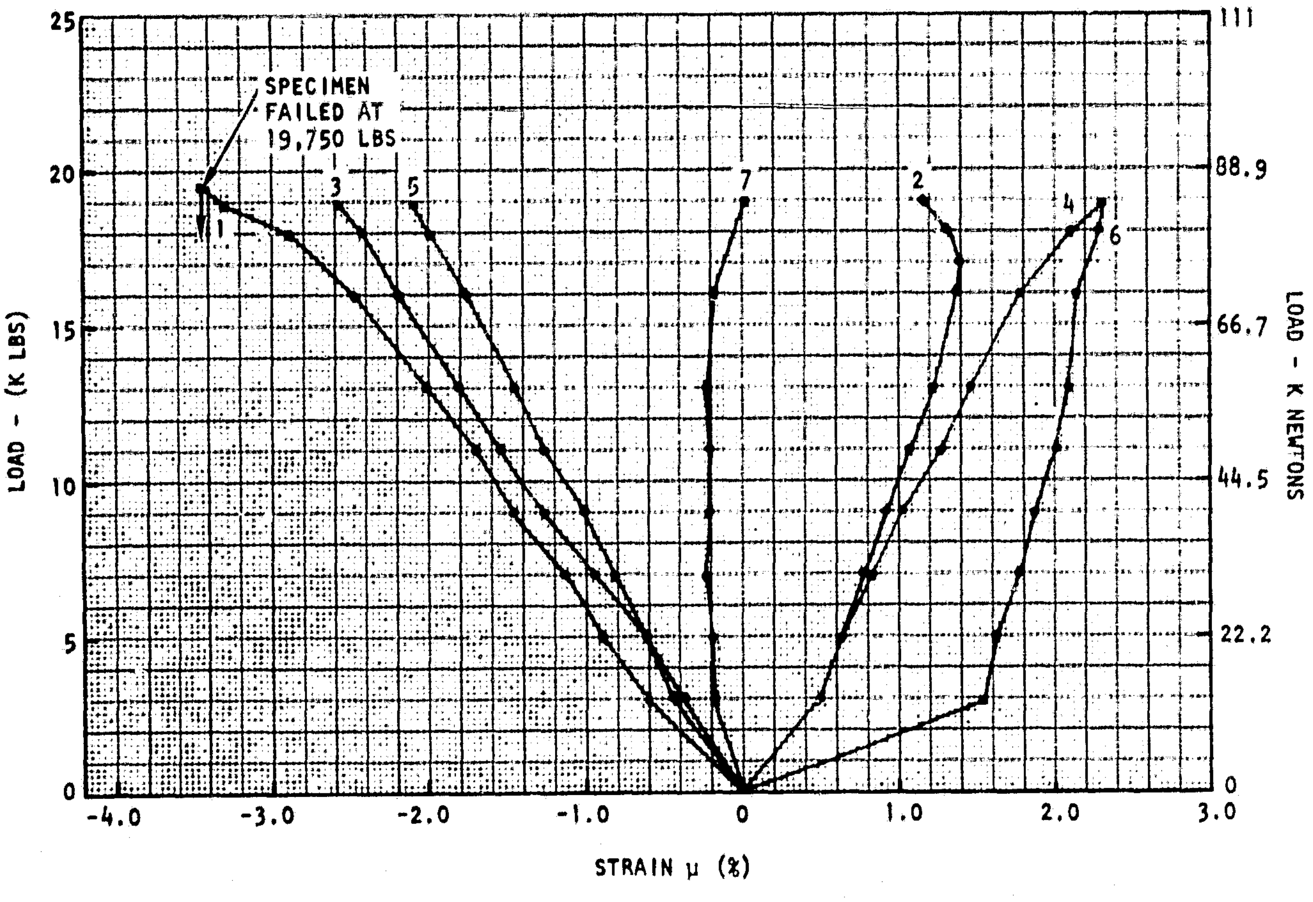


Figure 69. Compression Load/Strain Characteristics of "Hat" Stringer Stiffened Skin Element EX195-1PC at 316 C (600 F)

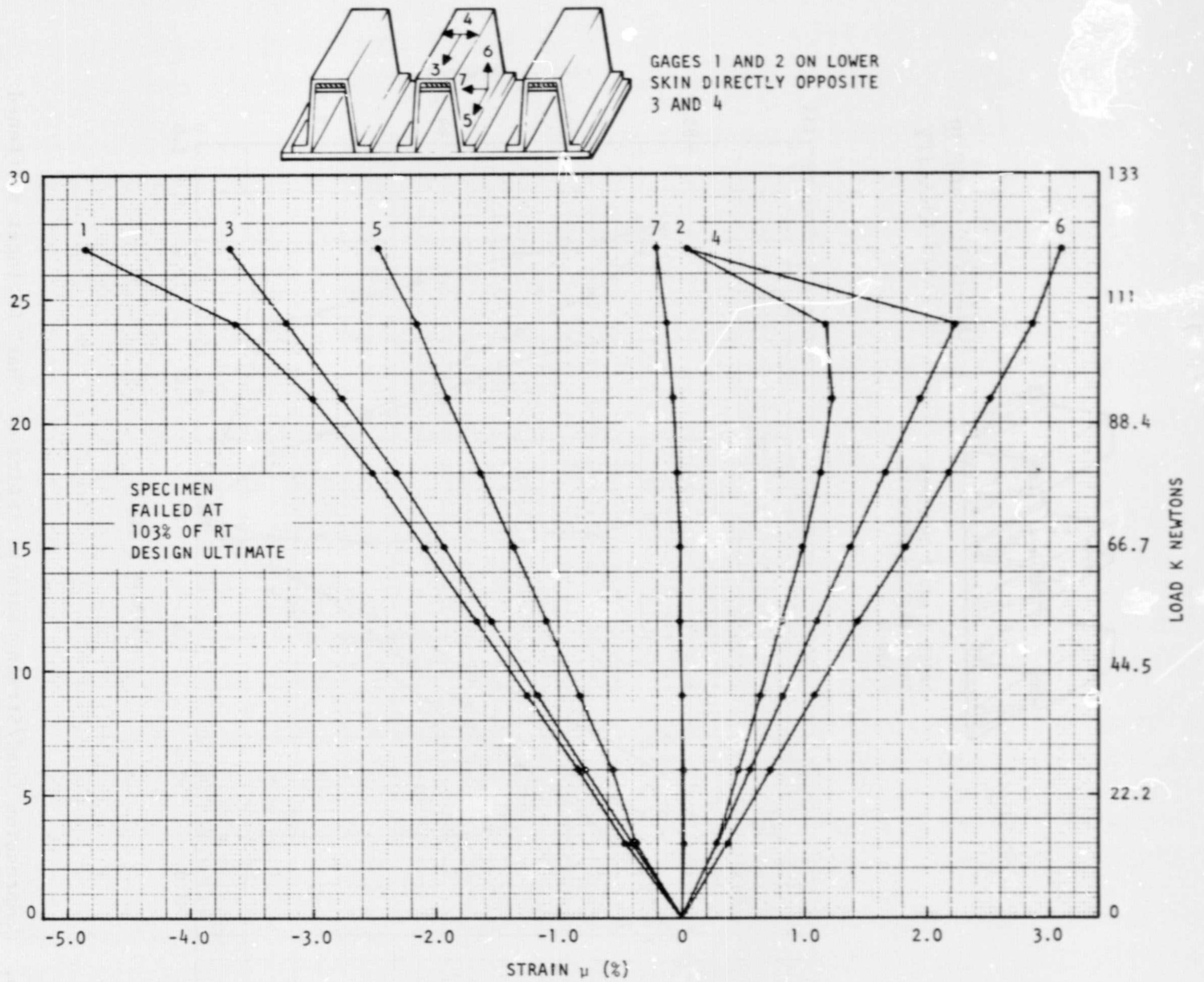
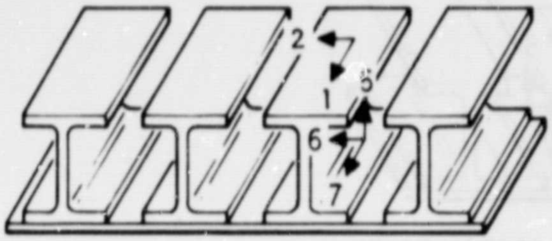


Figure 70. Compression Load/Strain Characteristics of "Hat" Stringer Stiffened Skin Element EX195-3A Aged for 125 Hours at at 316 C (600 F) and Tested at 316 C (600 F)

C-2



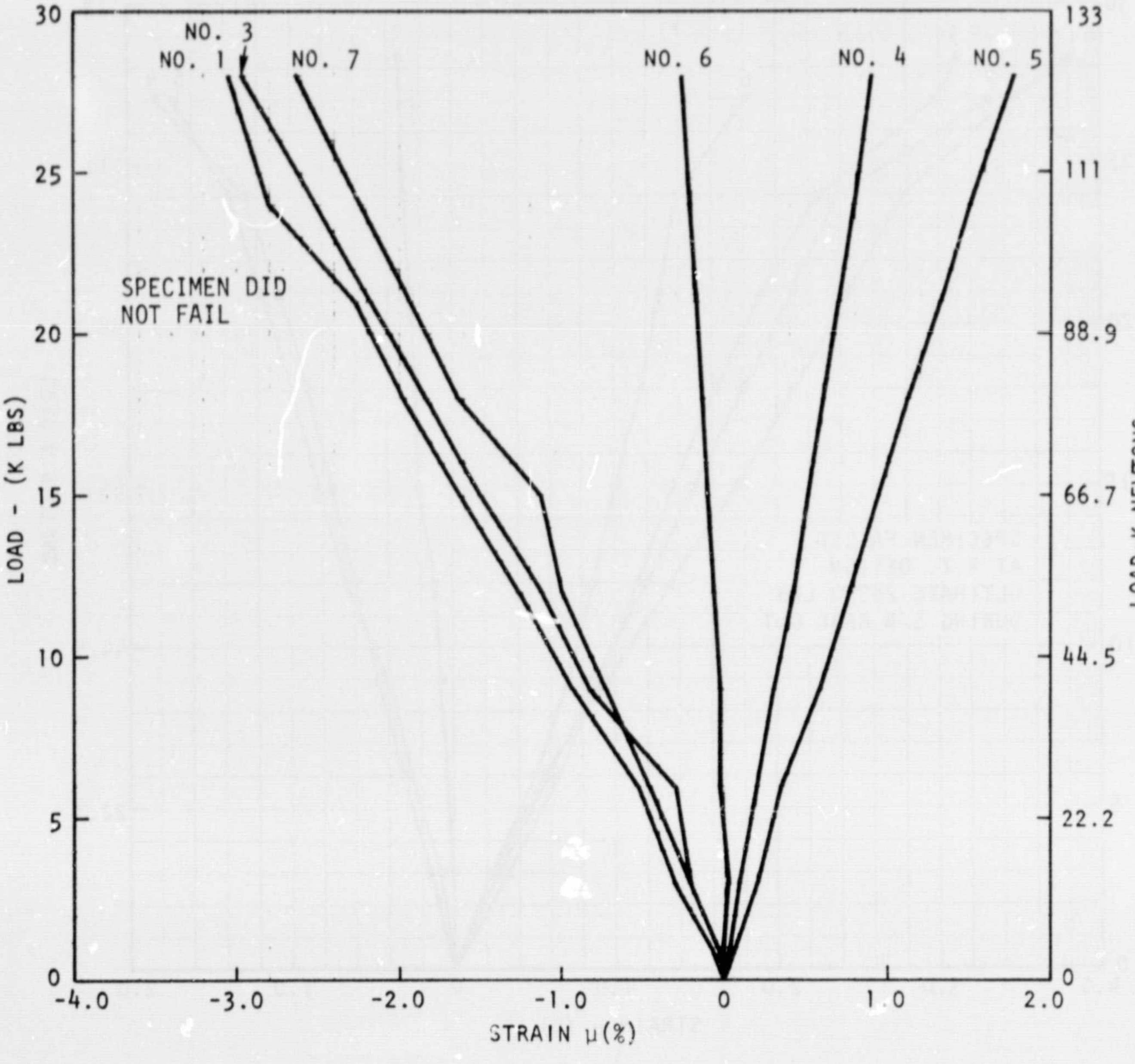
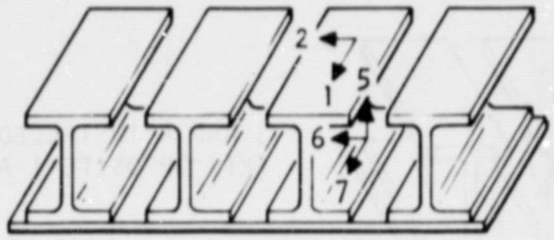


Figure 71. Load/Strain Characteristics of "I" - Stringer Stiffened Skin Element EX111/EX113 Tested at -132C (-270 °F)



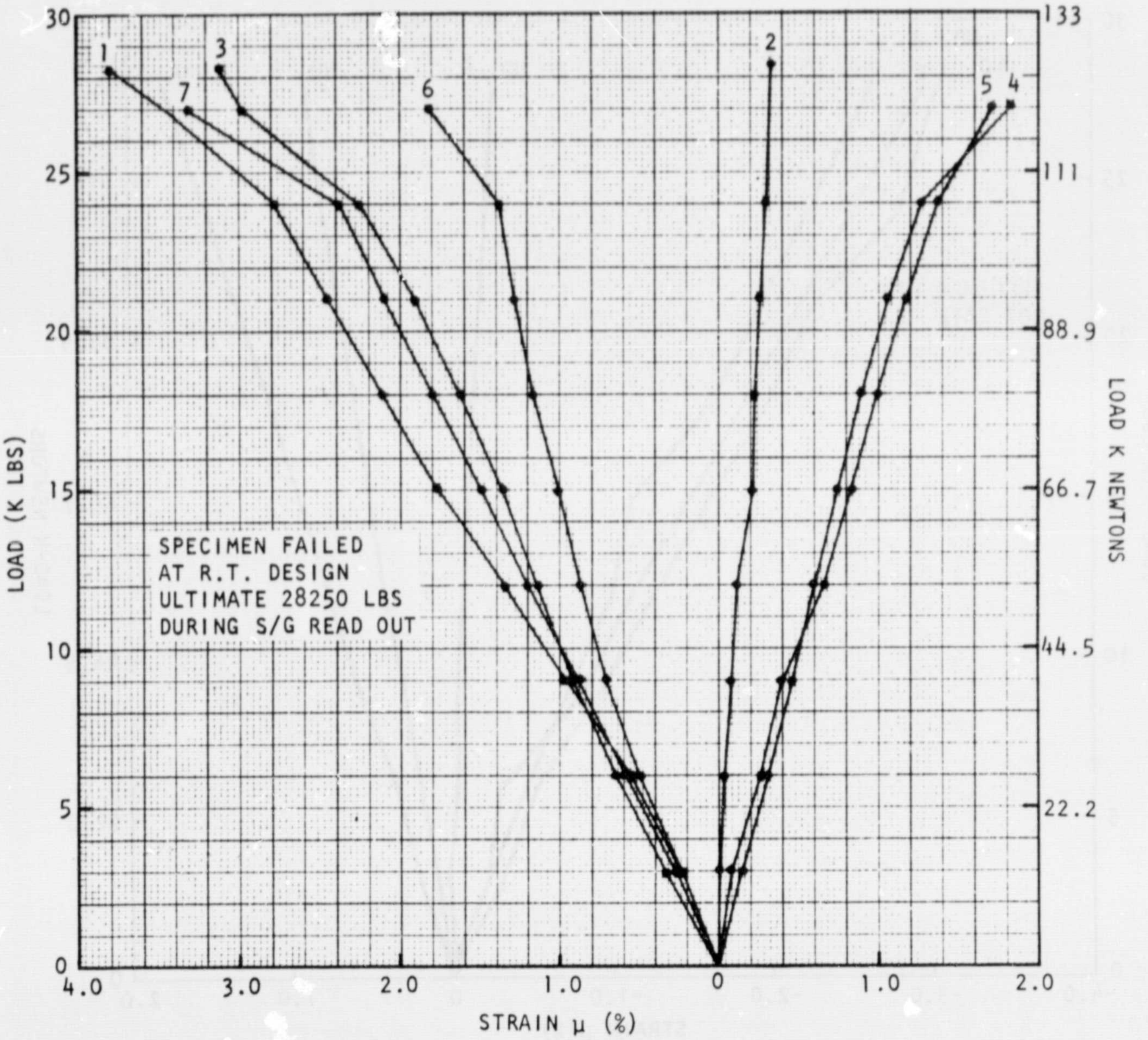


Figure 72. Compression Load/Strain Characteristics of "I" Stringer Stiffened Skin Element EX 194-4A Aged for 125 Hours at 316 C (600 F) and Tested at -132 C (-270 F)

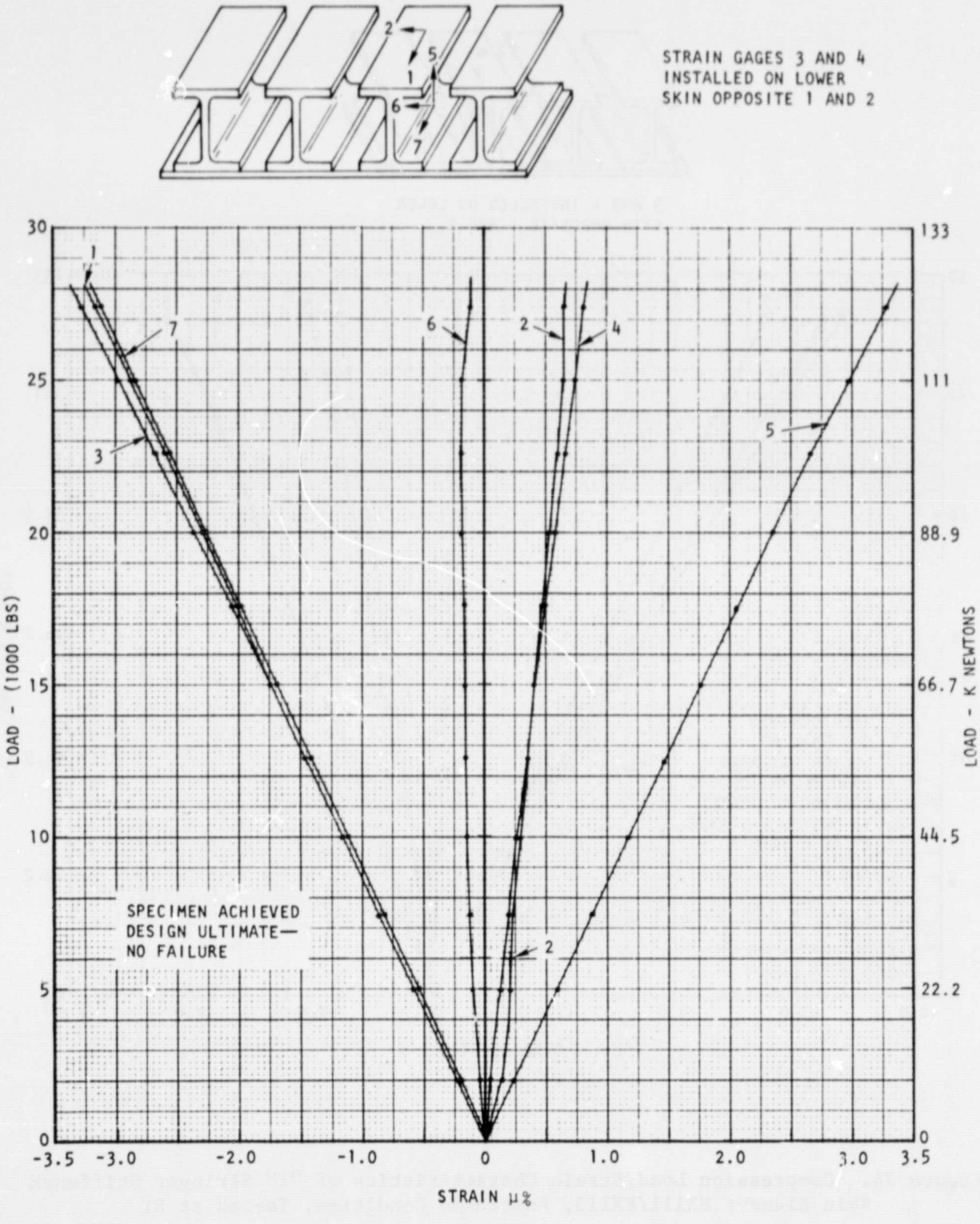
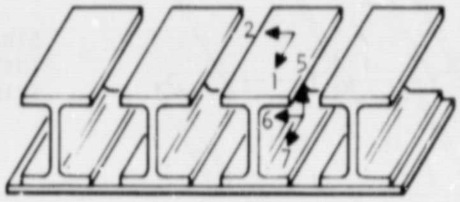


Figure 73. Compression Load/Strain Characteristics of "I"-Stringer Stiffened Skin Element EX111/EX113, Postcured Condition Tested at Room Temperature



3 AND 4 INSTALLED ON LOWER SKIN OPPOSITE 1 AND 2

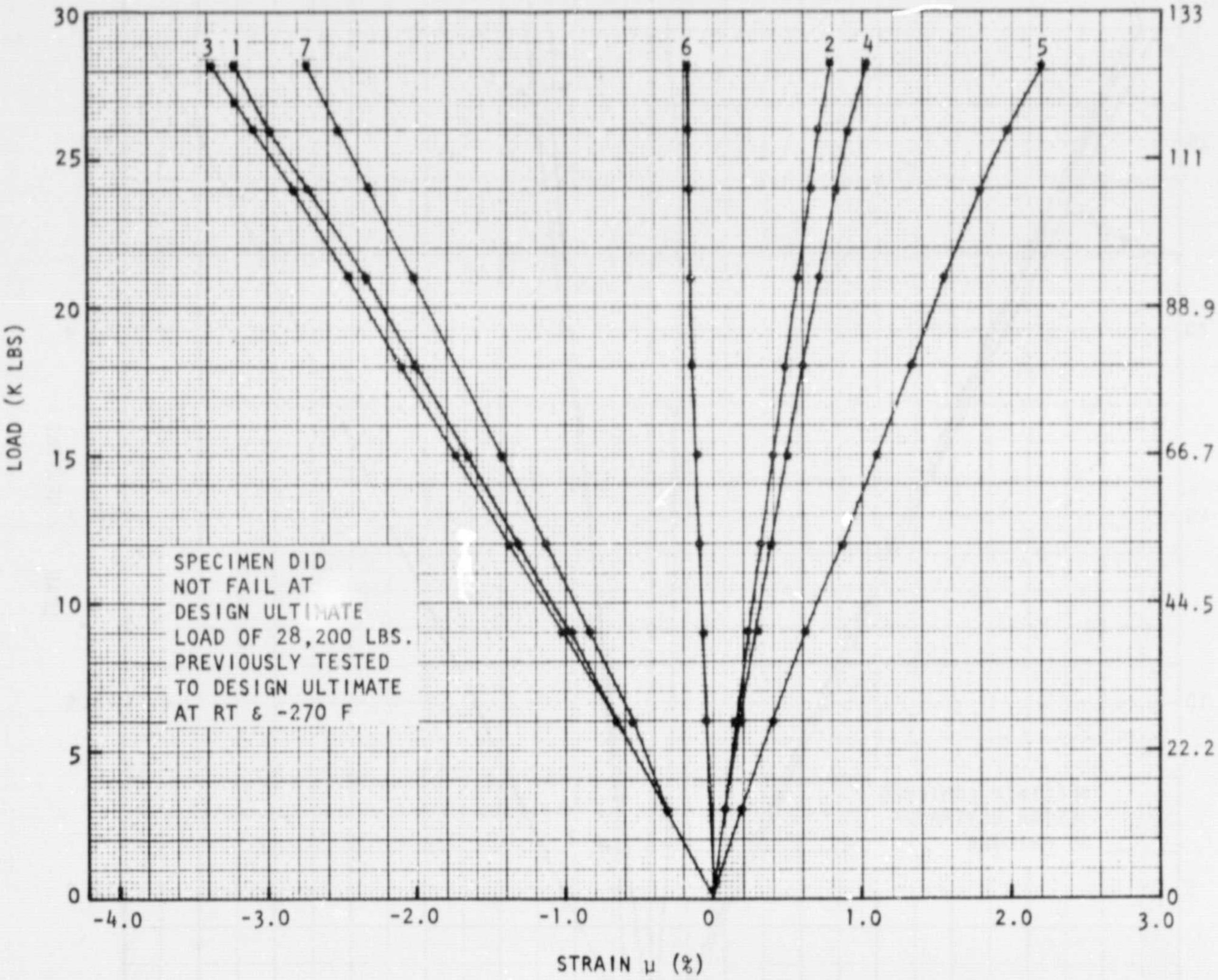


Figure 74. Compression Load/Strain Characteristics of "I" Stringer Stiffened Skin Element EX111/EX113, Postcured Condition, Tested at RT

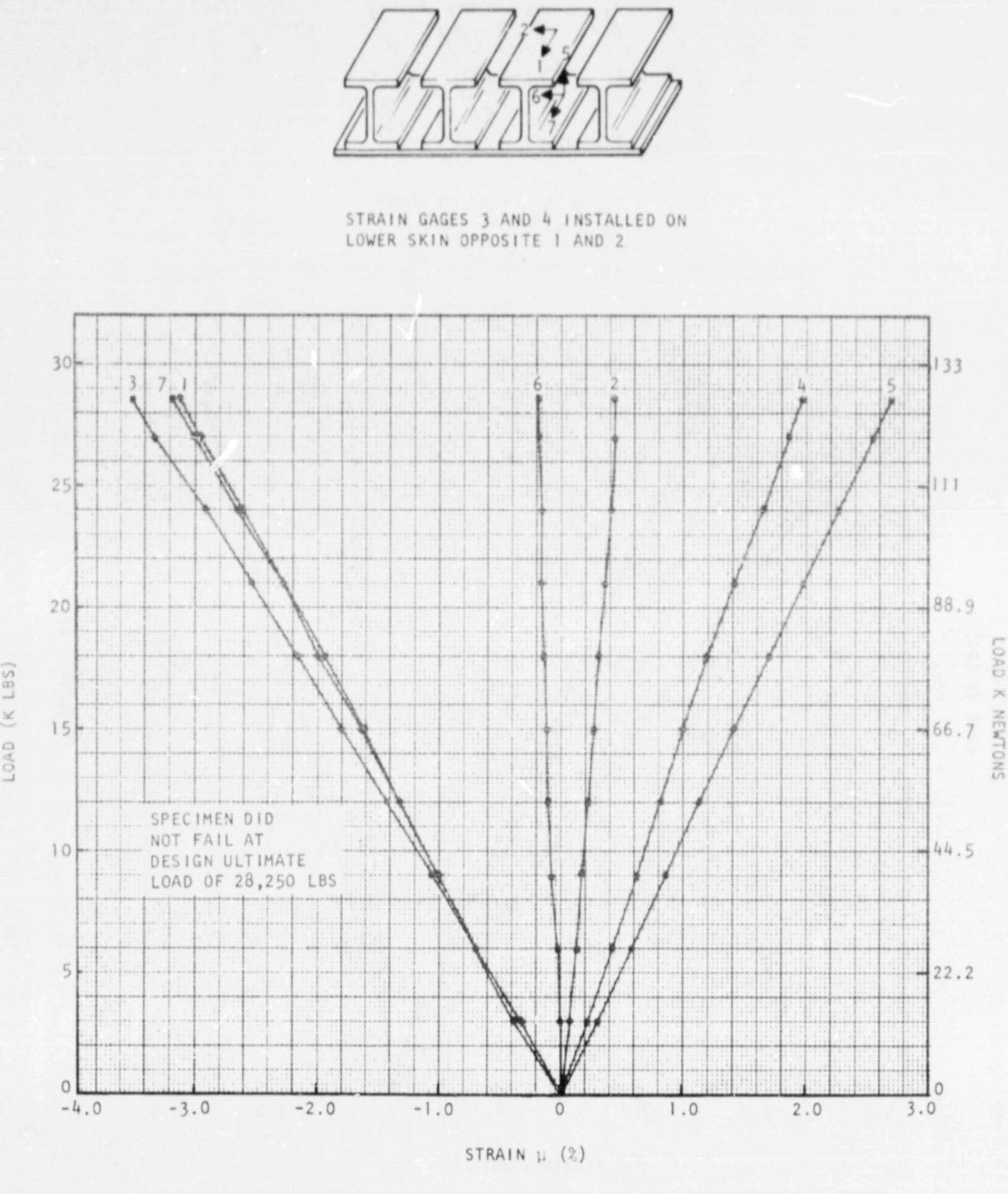
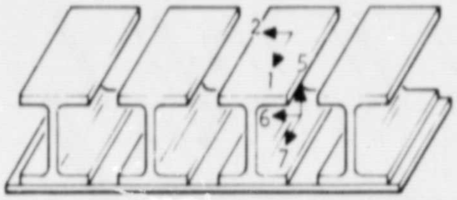


Figure 75. Compression Load/Strain Characteristics of "I" Stringer Stiffened Skin Element EX194-2A, Aged for 125 Hours at 316 C (600 F), and Tested at Room Temperature



GAGES 3 AND 4 INSTALLED ON LOWER SKIN OPPOSITE 1 AND 2

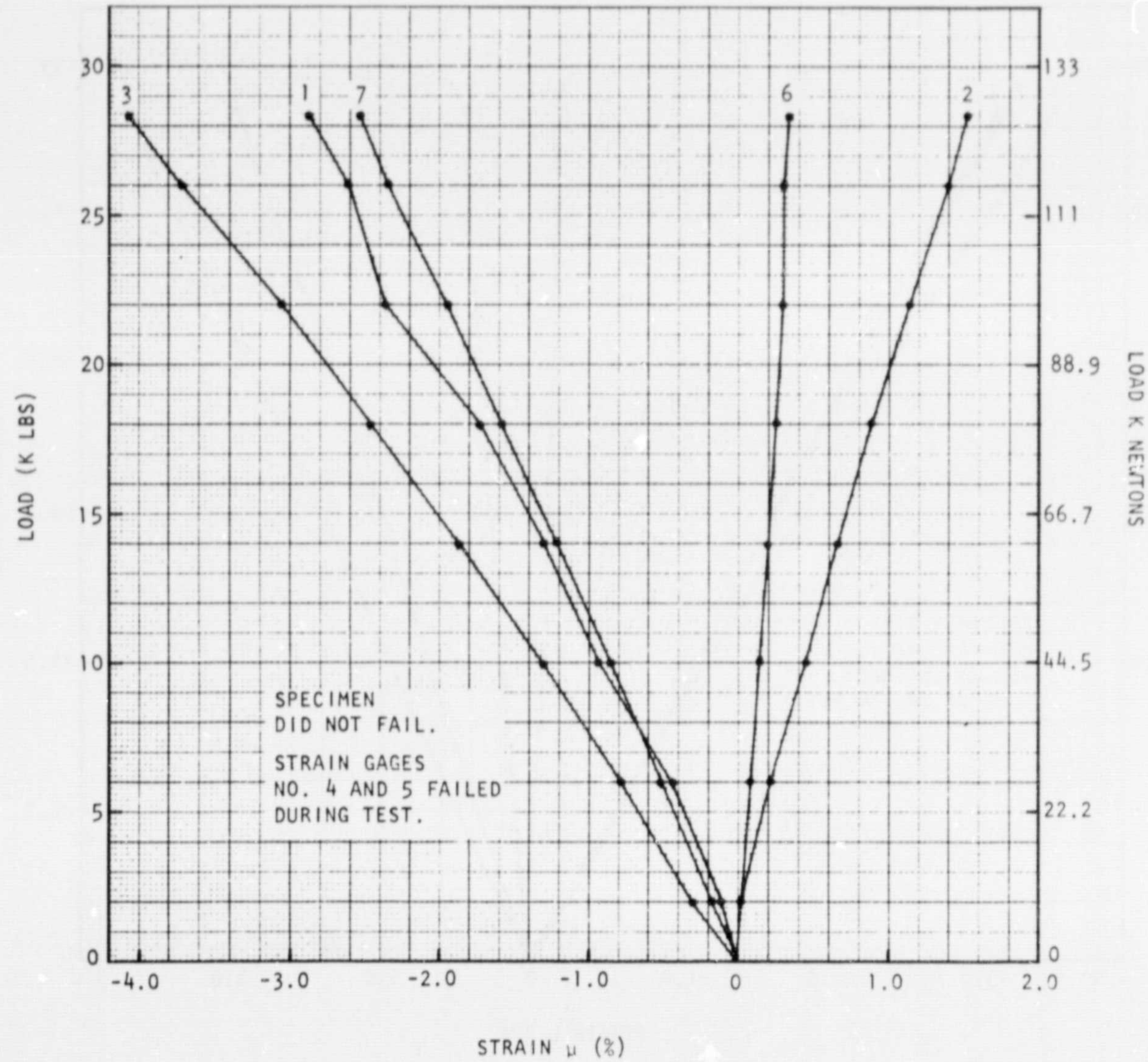
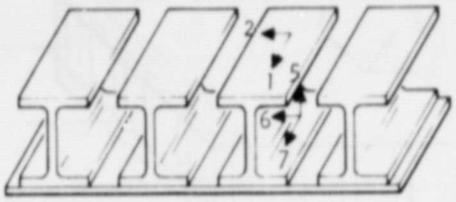


Figure 76. Load/Strain Characteristics of "I" Stringer Stiffened Skin Element EX194-1 Postcured Condition, Tested at 316 C (600 F).



STRAIN GAGES 3 AND 4 INSTALLED
ON LOWER SKIN OPPOSITE 1 AND 2

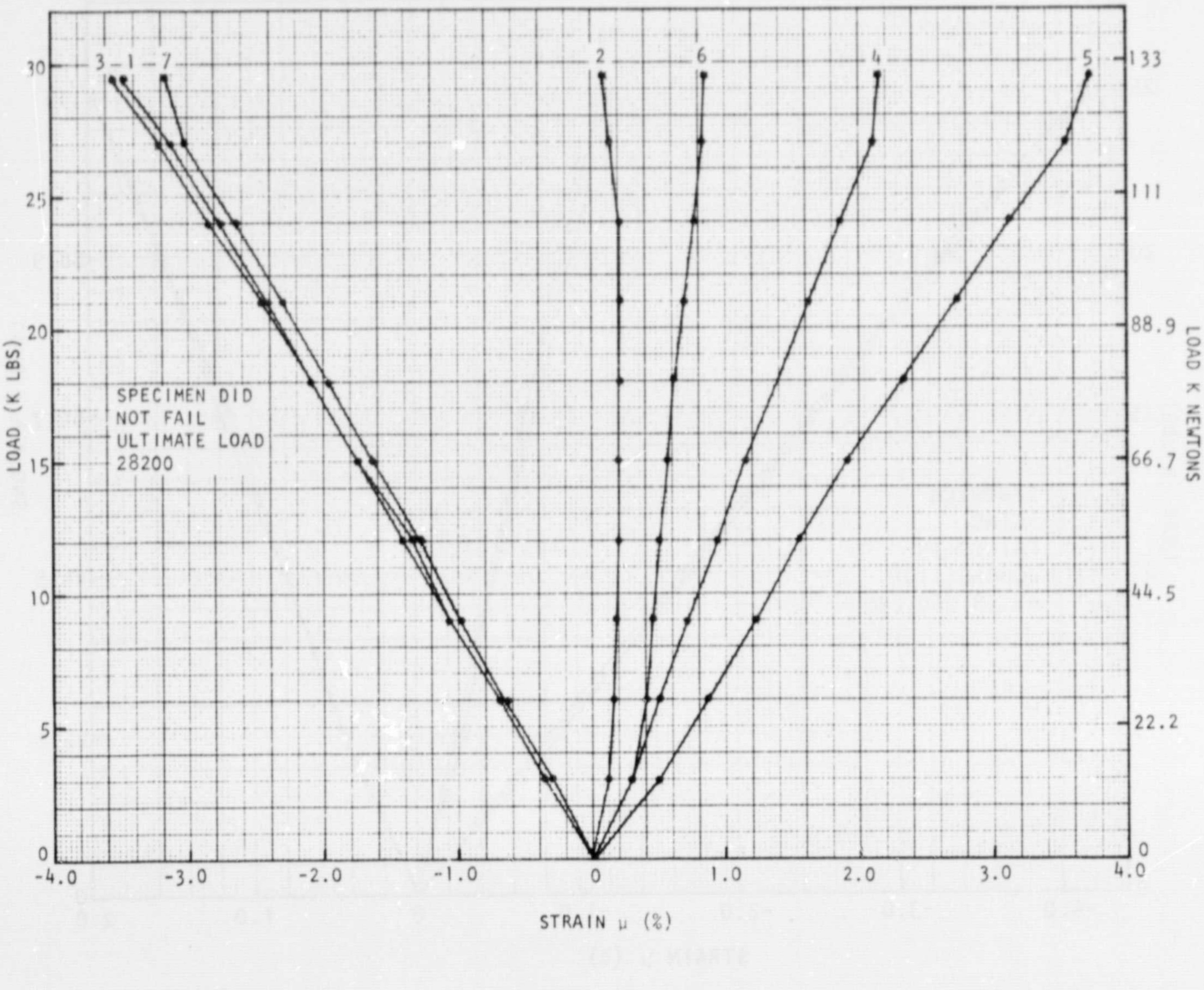


Figure 77. Load/Strain Characteristics of "I" Stringer Stiffened Skin Element EX194-3A, Aged for 125 Hours at 316 C (600 F) and Tested at 316 C (600 F).

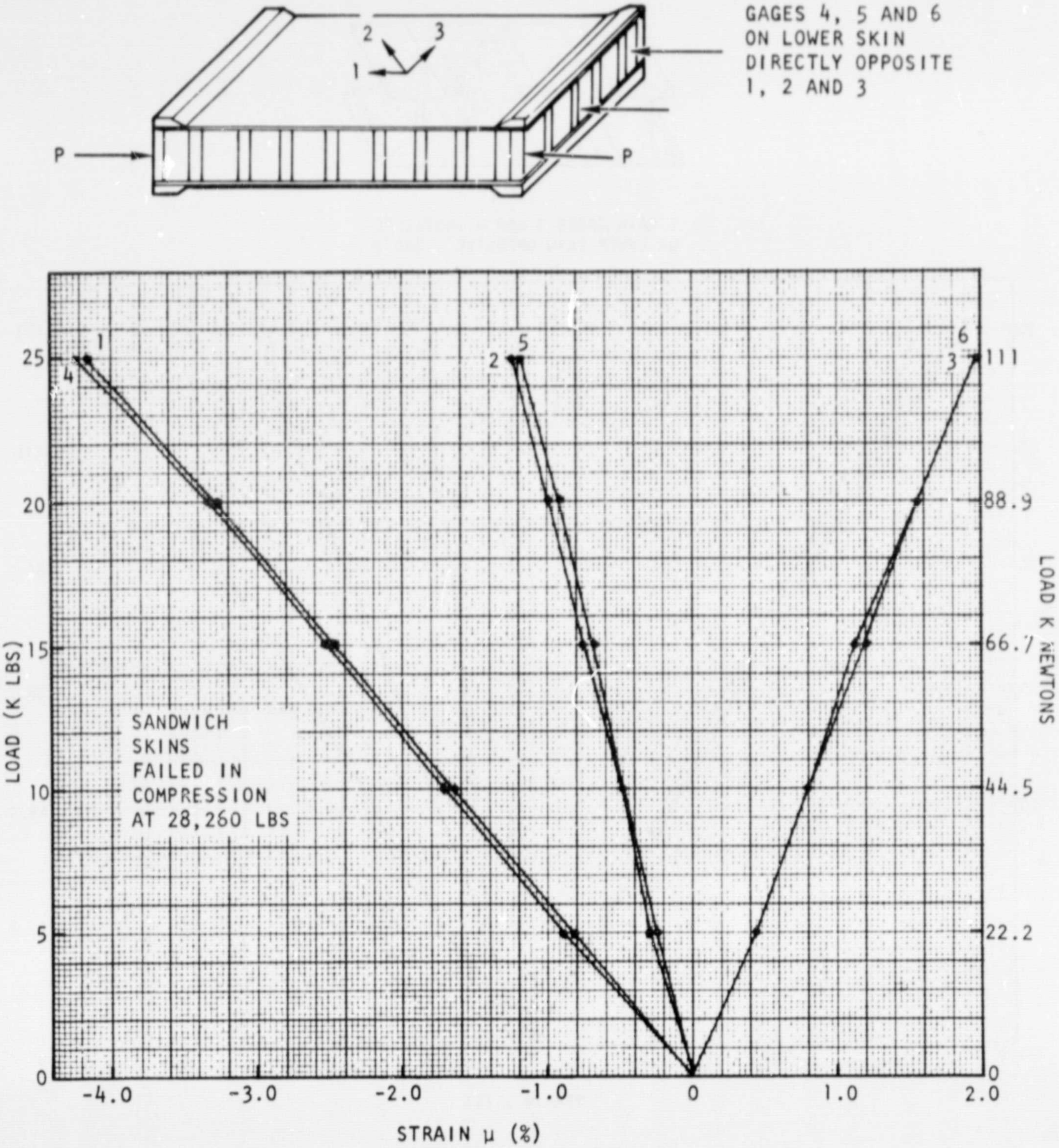
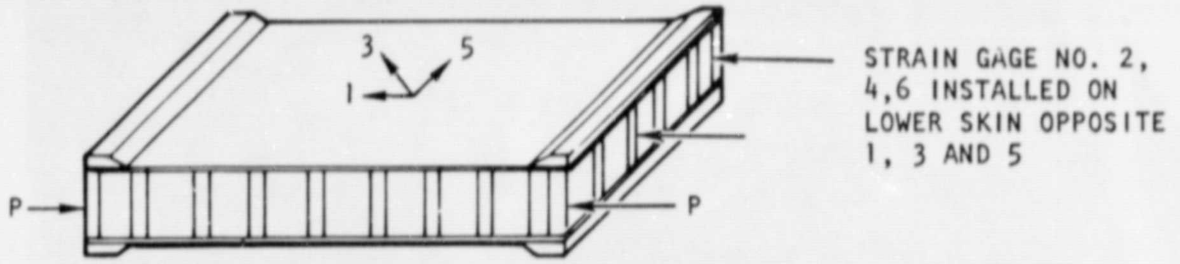


Figure 78. Load/Strain Characteristics of Sandwich Panel Element EX150-1, Postcured Condition, Tested at Room Temperature



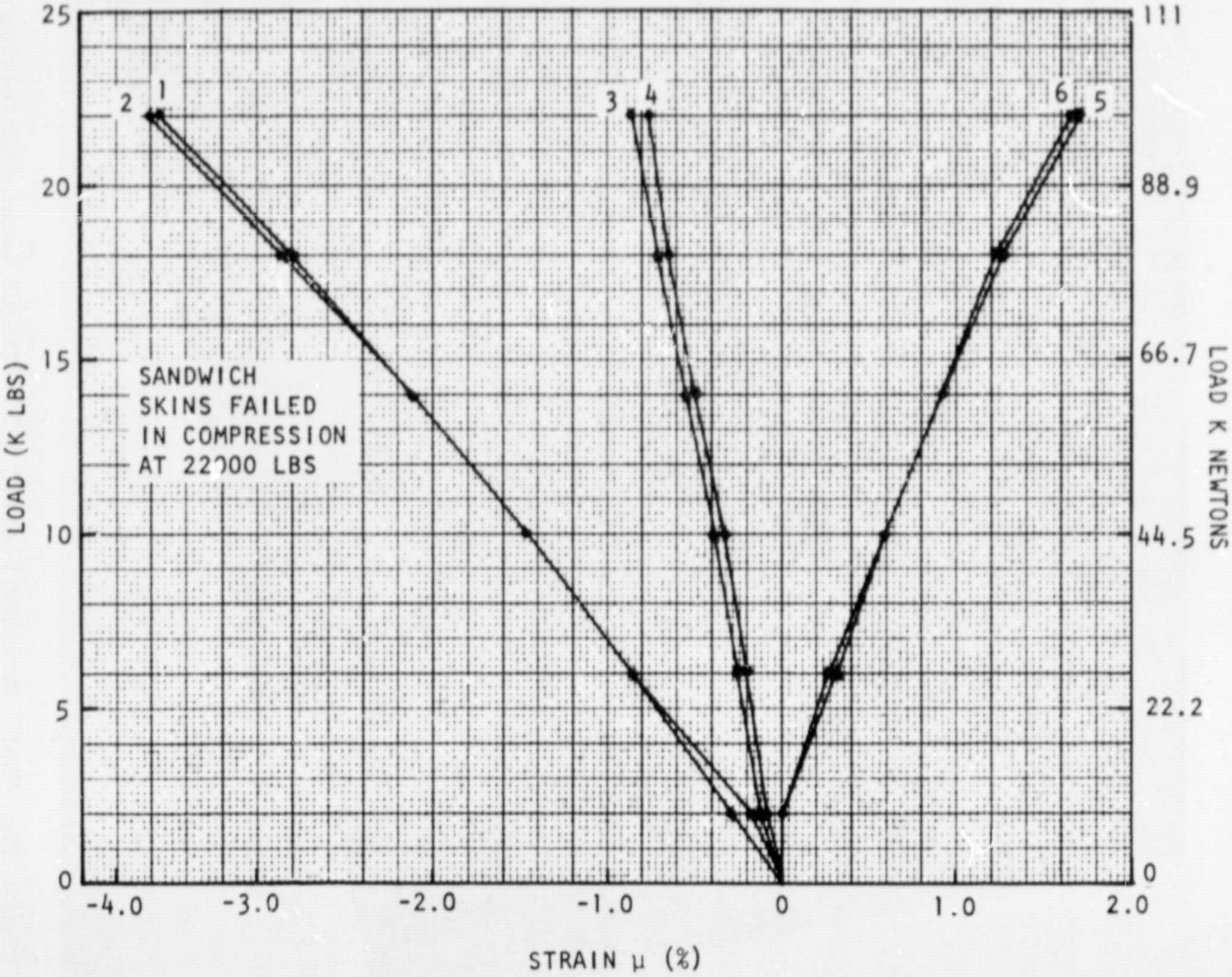


Figure 79. Load/Strain Characteristics of Sandwich Element, EX150-2 Postcured Condition, Tested at 316 C (600 F)

Figure 80. "Hat" Stringer Element EX109/EX110B Local Compression Failure, -132°C (-270°F) Test, Postcured.

A800331G-7C

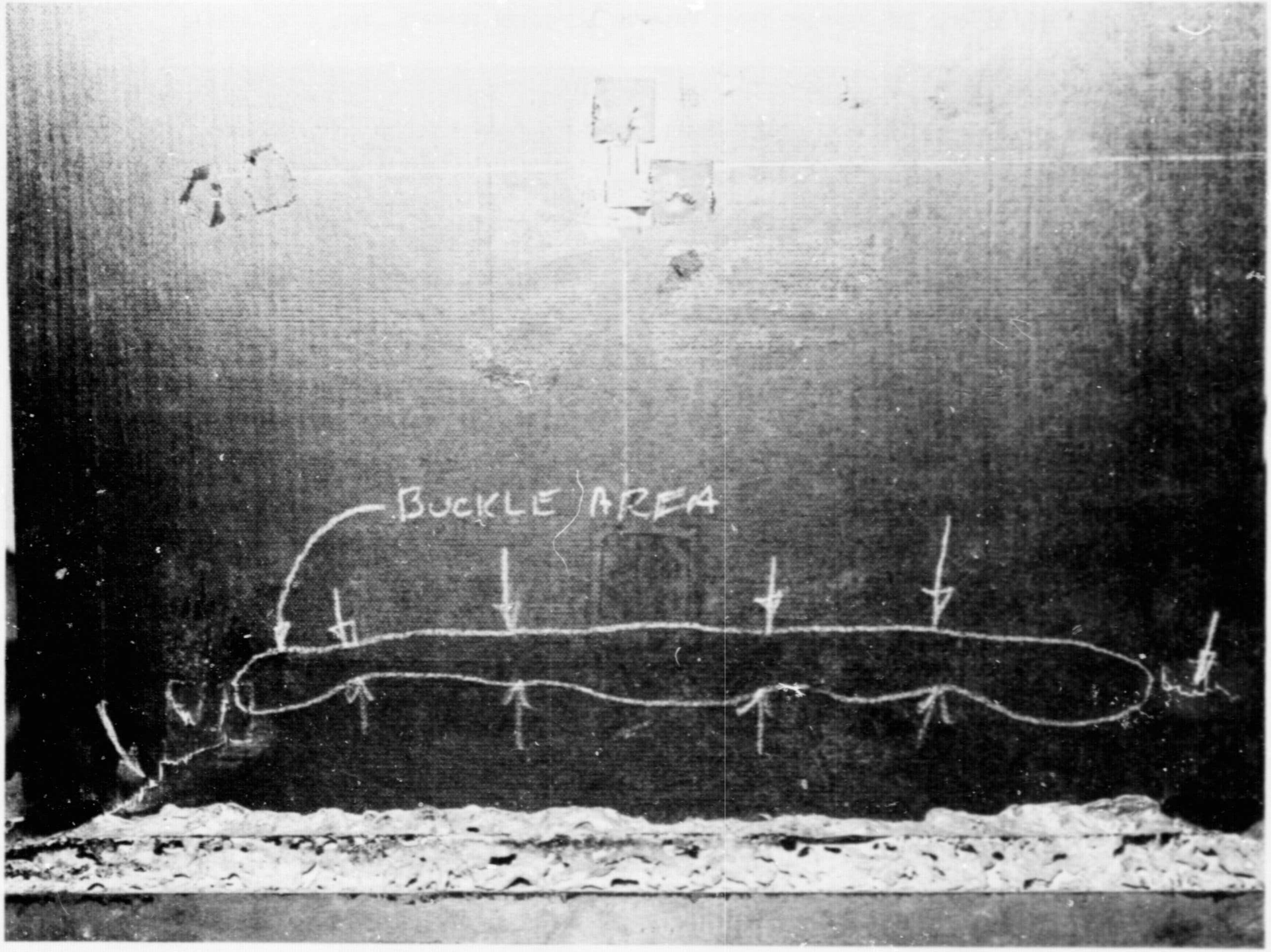


Figure 81. "Hat" Element EX195-1PC Showing Skin Compression and Buckling Failures, 316 C (600 F) Test, Postcured

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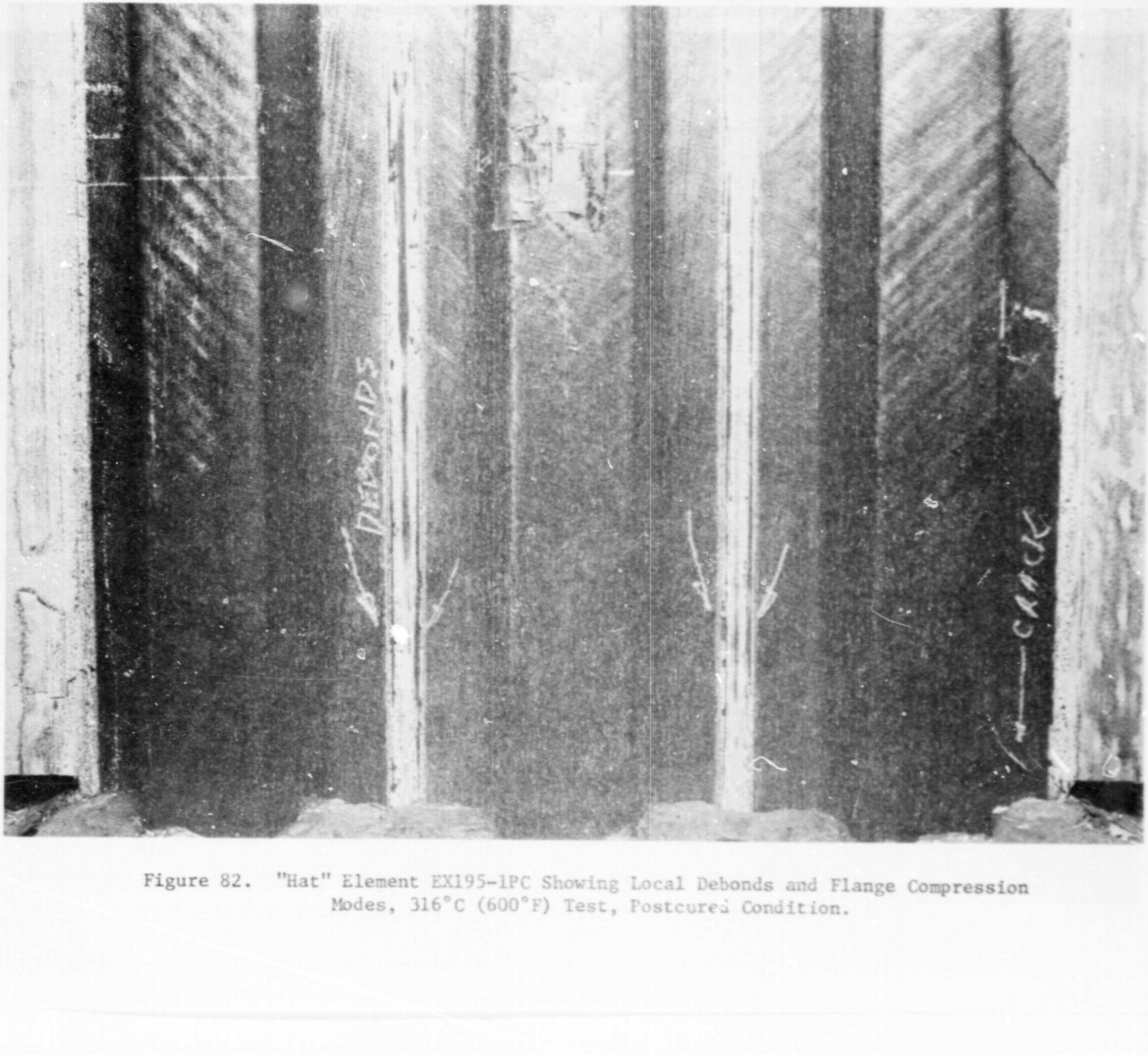

Figure 82. "Hat" Element EX195-1PC Showing Local Debonds and Flange Compression Modes, 316°C (600°F) Test, Postcured Condition.

Figure 83. "Hat" Element EX195-3A Showing Local Flange Compression Modes, 316°C (600°F) Aged Condition.

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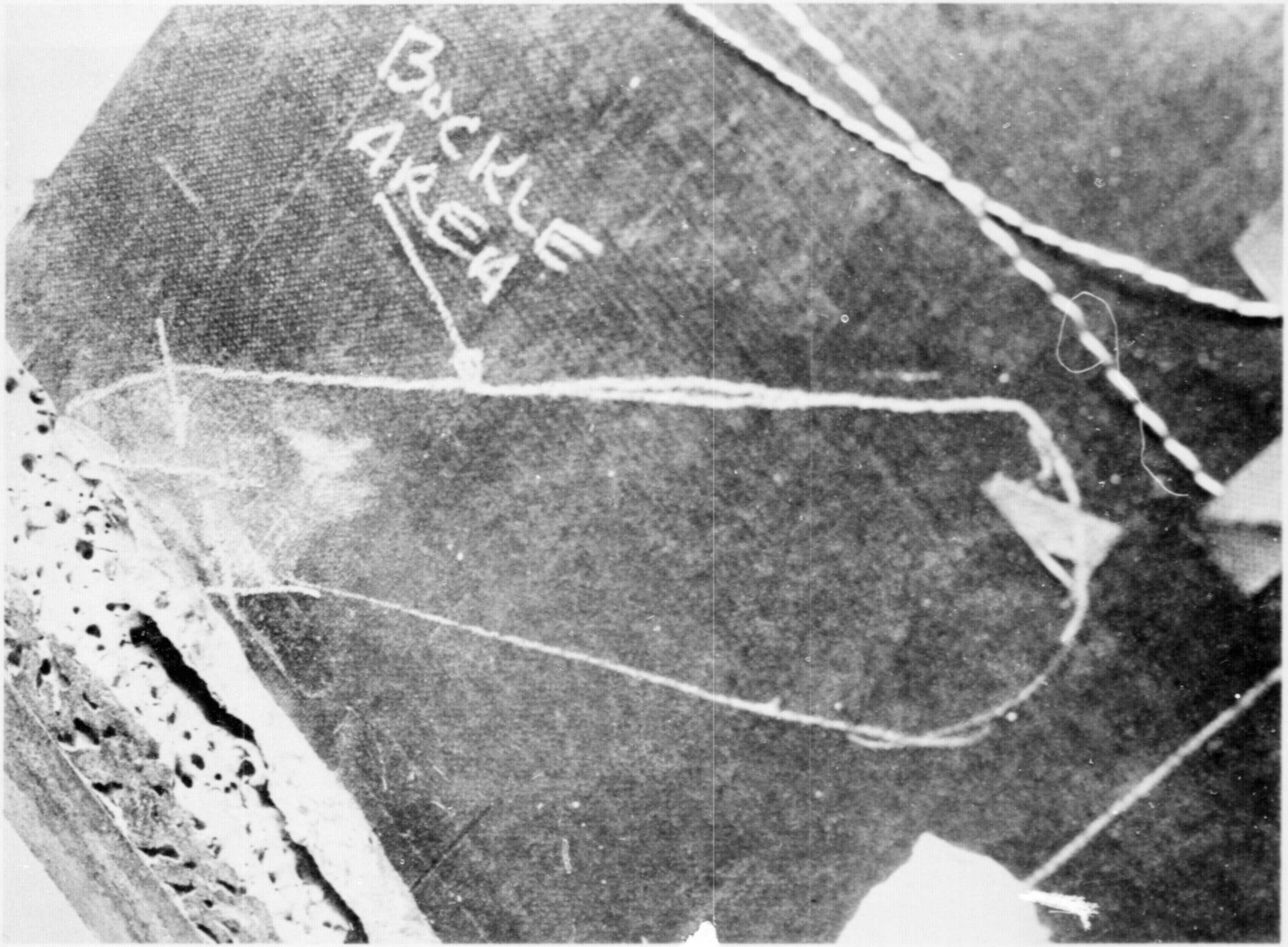

Figure 84. "Hat" Element EX195-3A, Local Skin Compression and Buckling Failure, 316°C (600°F) Test, Aged Condition.

Figure 85. "I" Element EX194-1PC Showing Local Skin Compression Failure, 316 C (600 F) Test Postcured

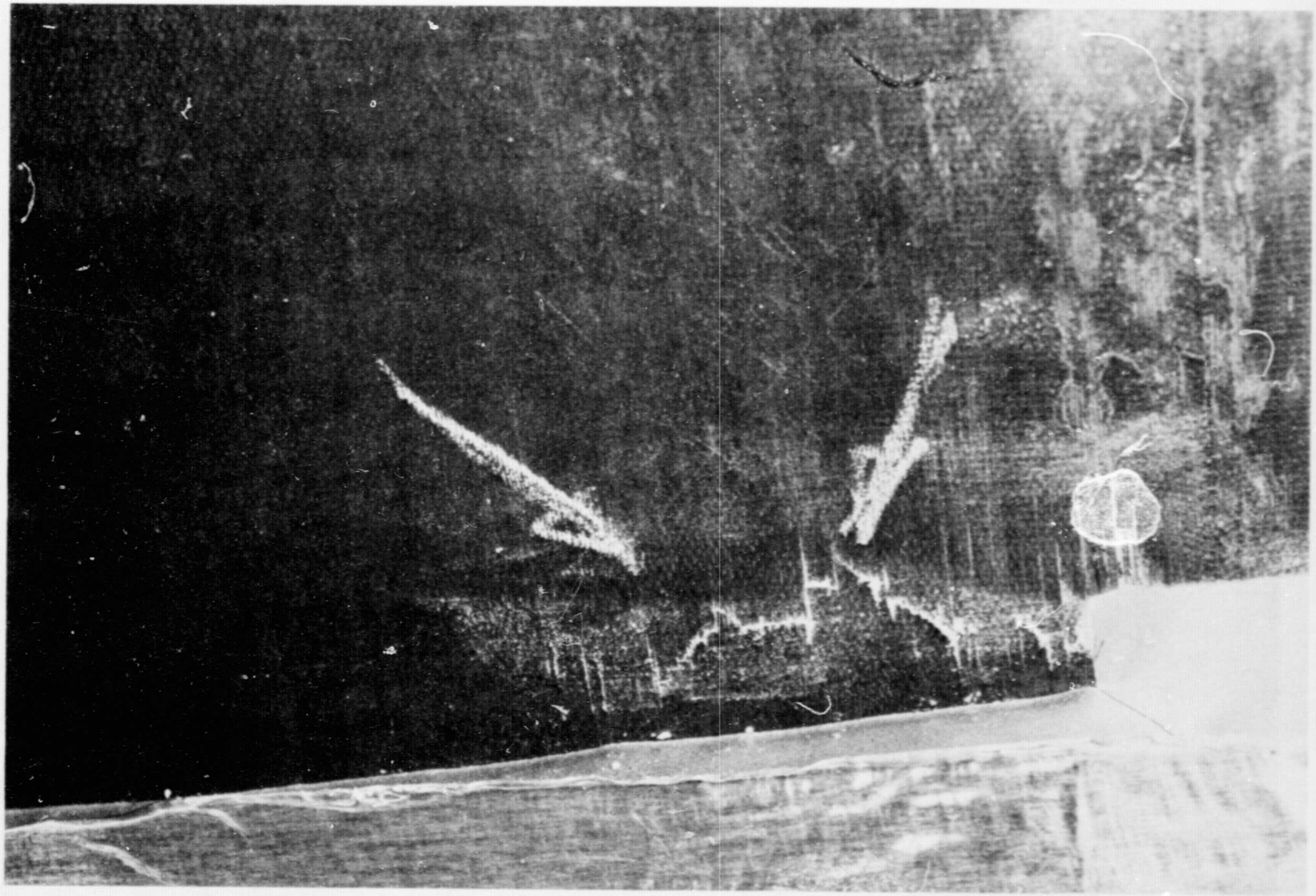

Figure 86. Skin Compression Failure "I" Stringer Element EX194-4A -132°C (-270°F) Test, Aged Condition.

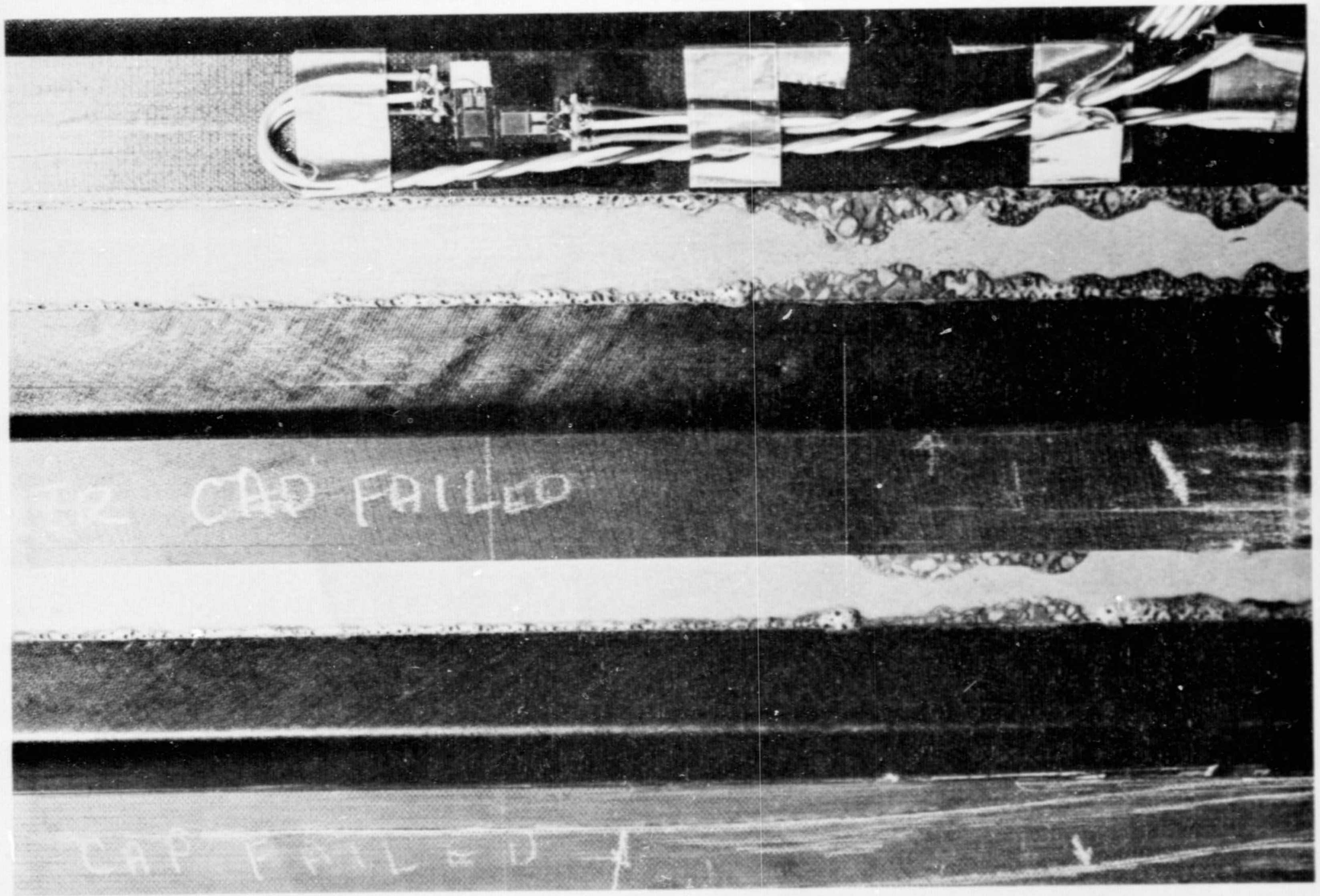

Figure 87. Cap Compression Failure, "I" Element EX194-4A, -132°C (-270°F) Test, Aged Condition

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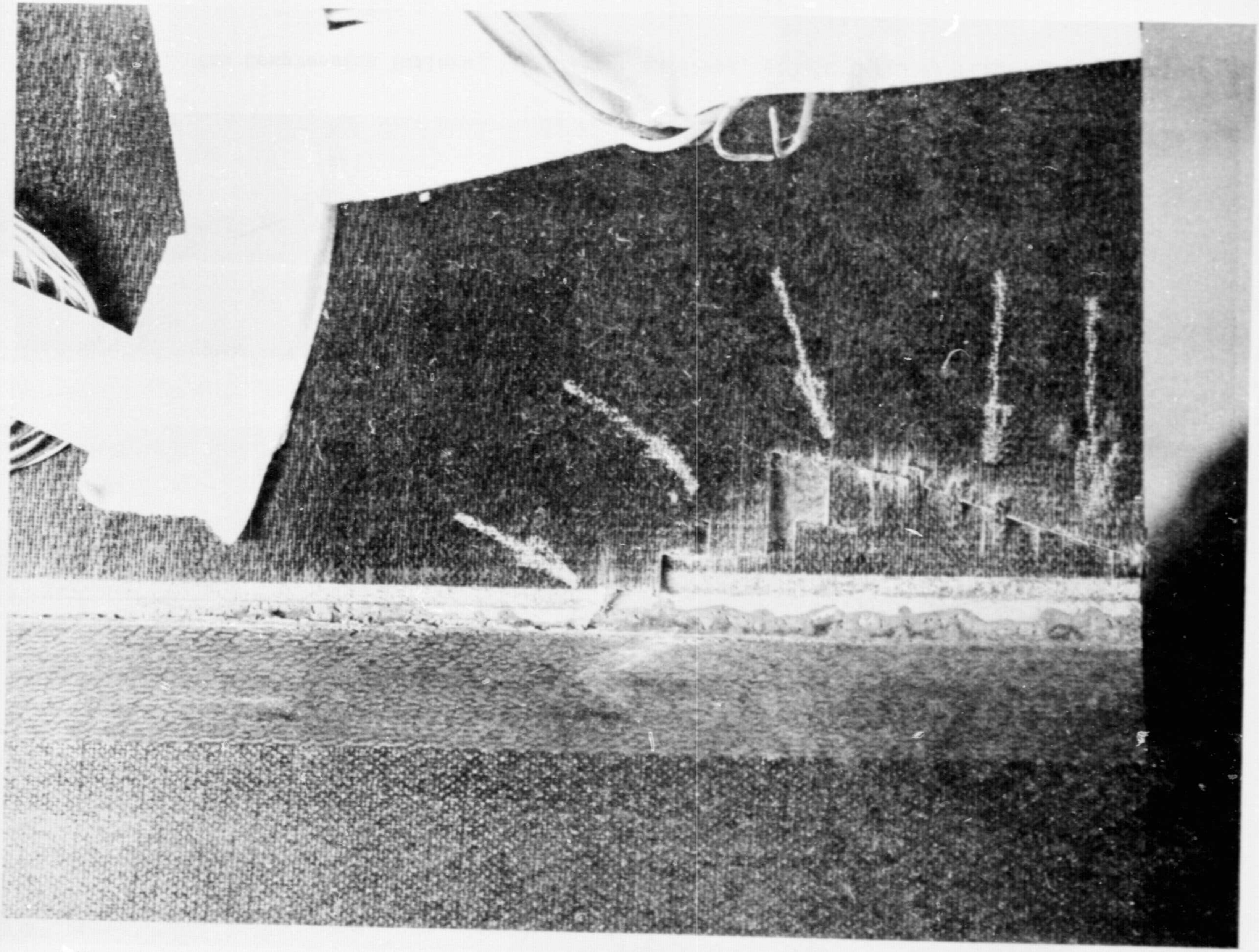


Figure 88. Local Compressive Failure—Sandwich Element EX150-1, RT Test, Side 2, Postcured.

A800331G-5C

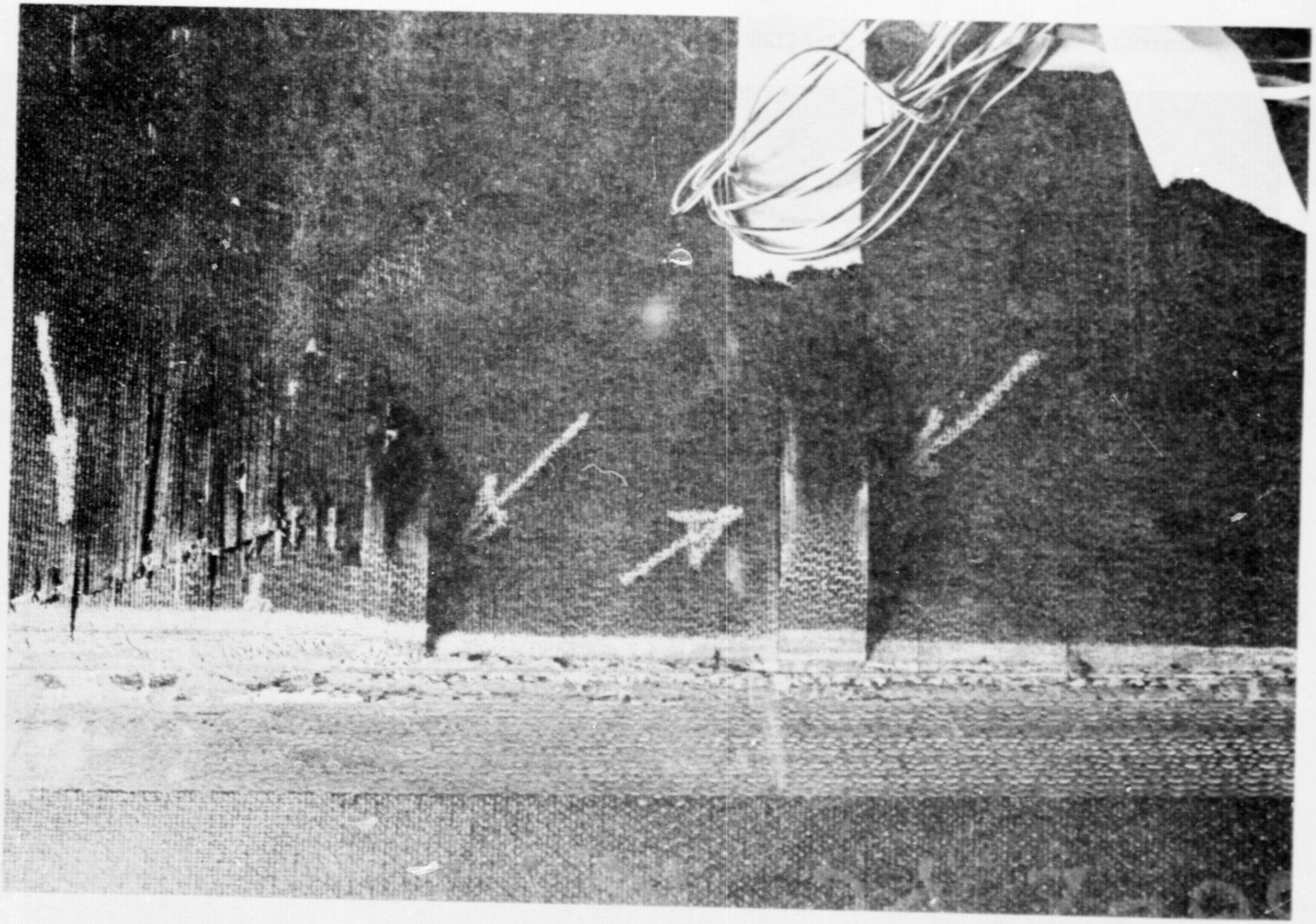


Figure 89. Compressive Failure Mode Sandwich Element EX150-1, RT Test, Side 1, Postcured.

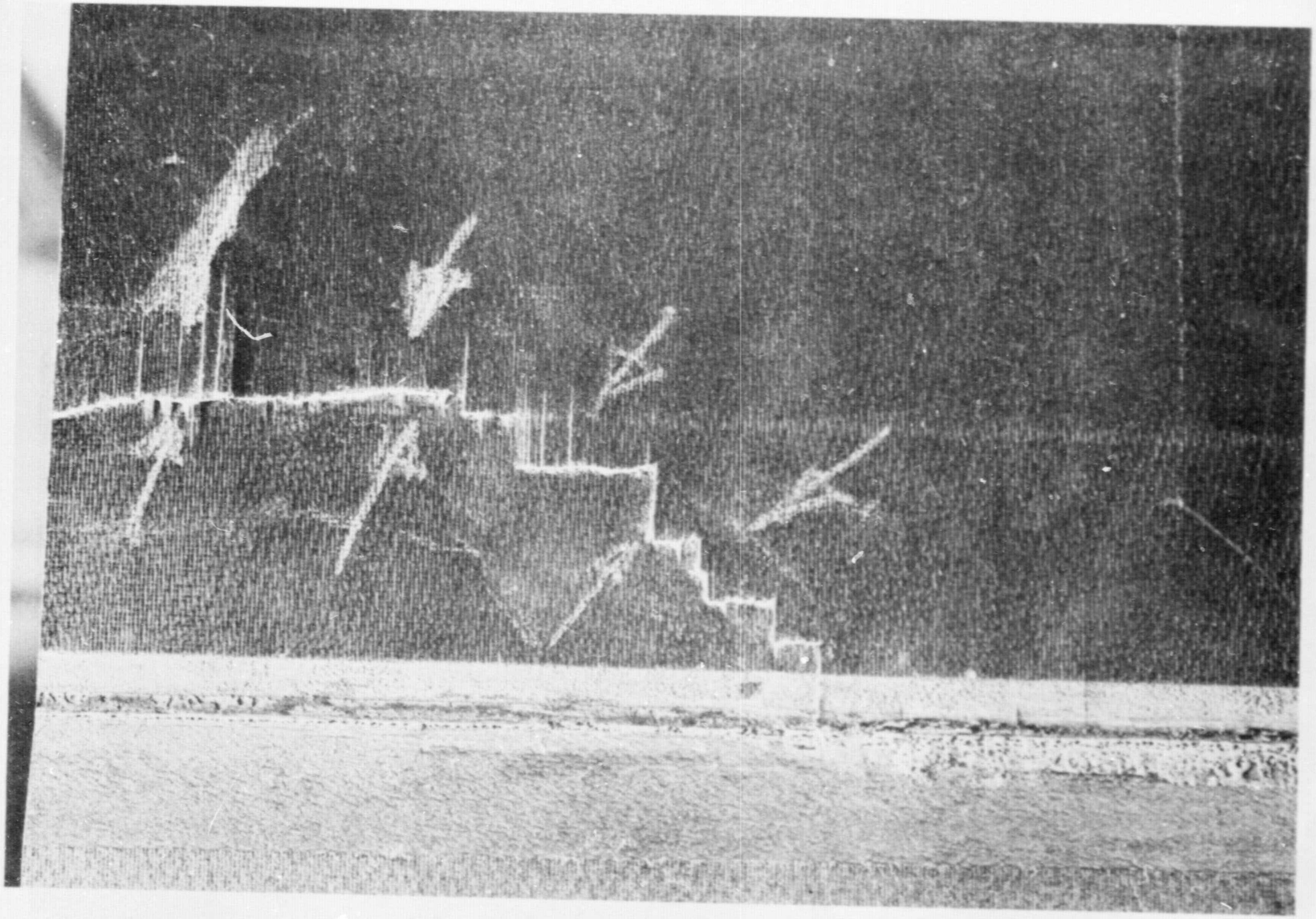
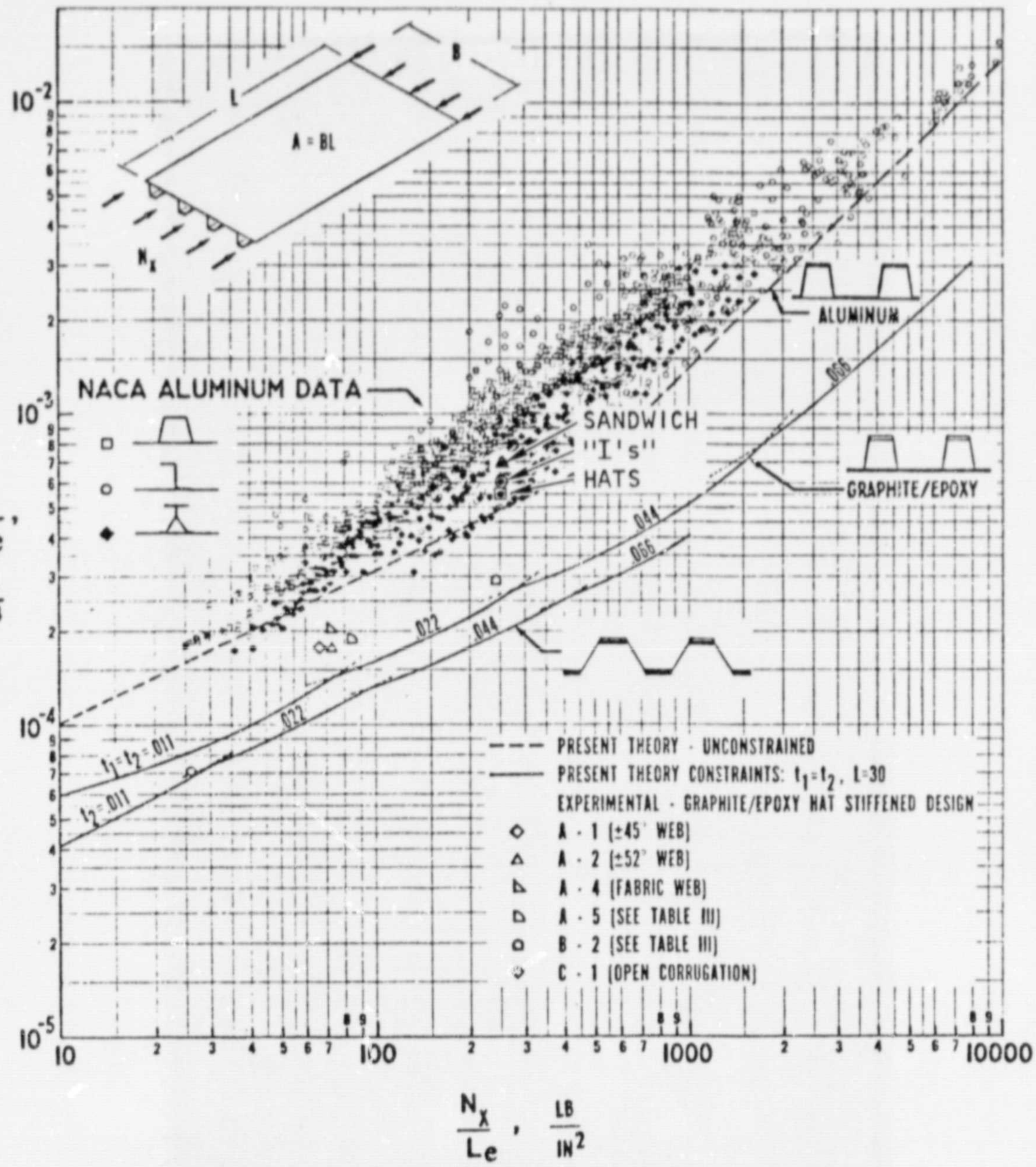


Figure 90. Local Compressive Failure Sandwich Element EX150-2, 316°C (600°F) Test, Postcured.



REF. "ANALYTICAL AND EXPERIMENTAL STUDY OF STRUCTURALLY EFFICIENT COMPOSITE HAT-STIFFENED PANELS LOADED IN AXIAL COMPRESSION"

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JERRY G. WILLIAMS &
MARTIN M. MIKULAS, JR.
NASA-LARC
AIAA PAPER #75-754, 1975

Figure 91. Comparison of Structural Efficiencies of Compression Panels.

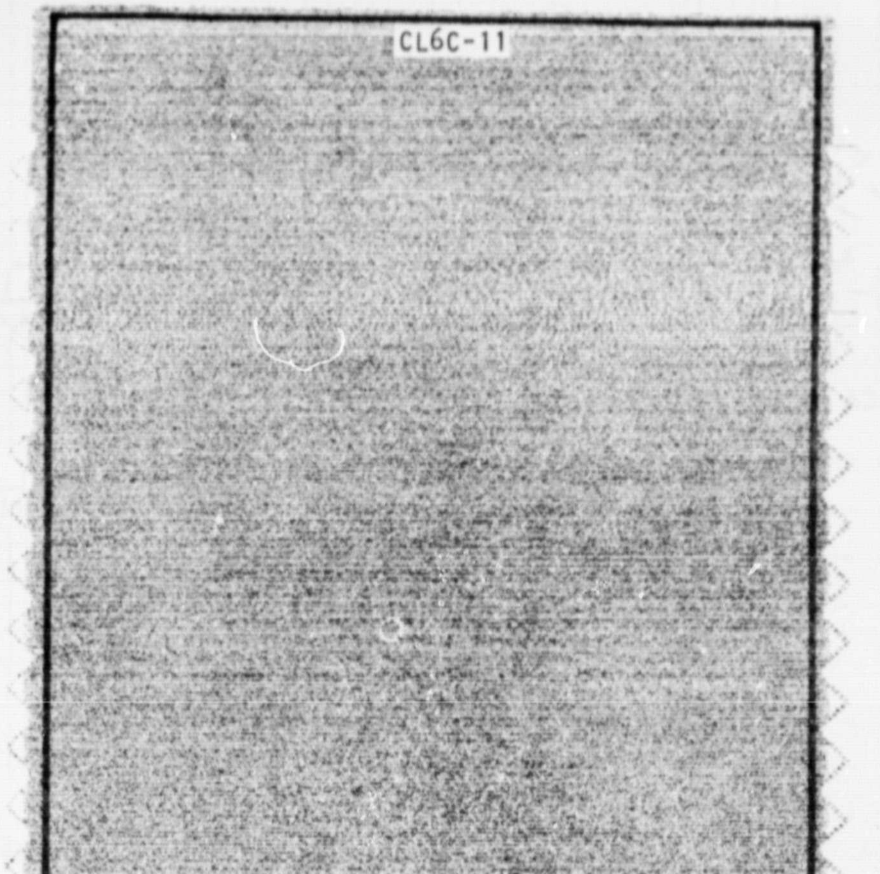

Figure 92. C-Scan Laminate CL 6C-11, $(0,\pm45)_s$, 6 Plies

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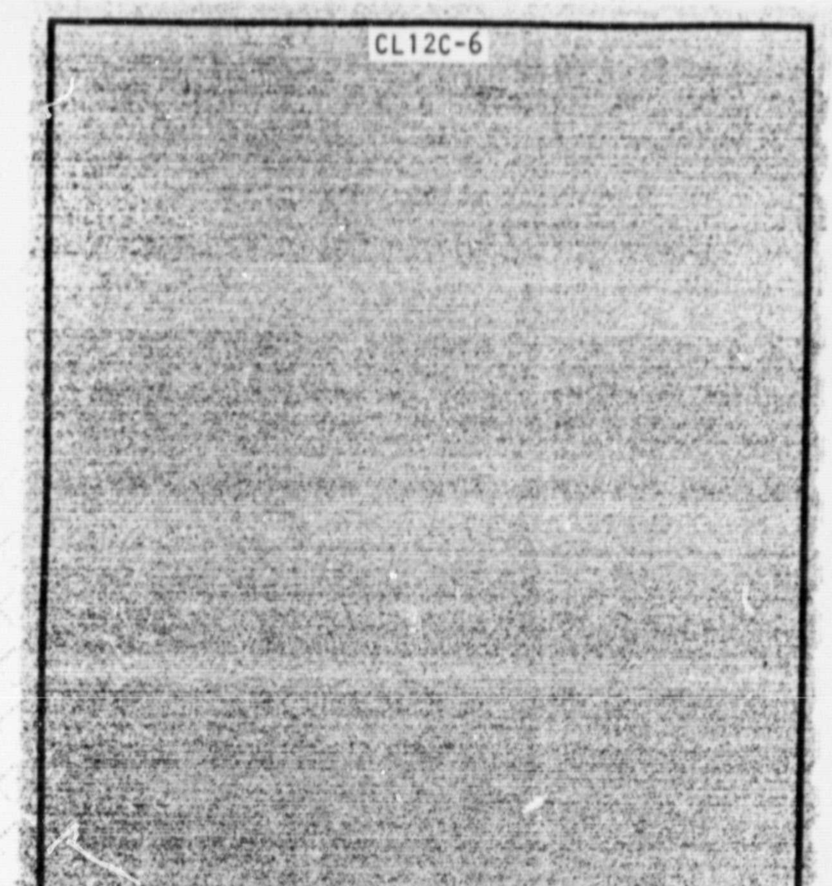

Figure 93. C-Scan Laminate CL 12C-6, $(0,\pm45)_s$, 12 Plies

Figure 94. C-Scan Laminate CL 24C-7, $(0\underline{+}45)_s$, 24 Plies

Figure 95. C-scan Laminate CL8C-10, $(0,\pm45,90)_S$, 8 Plies

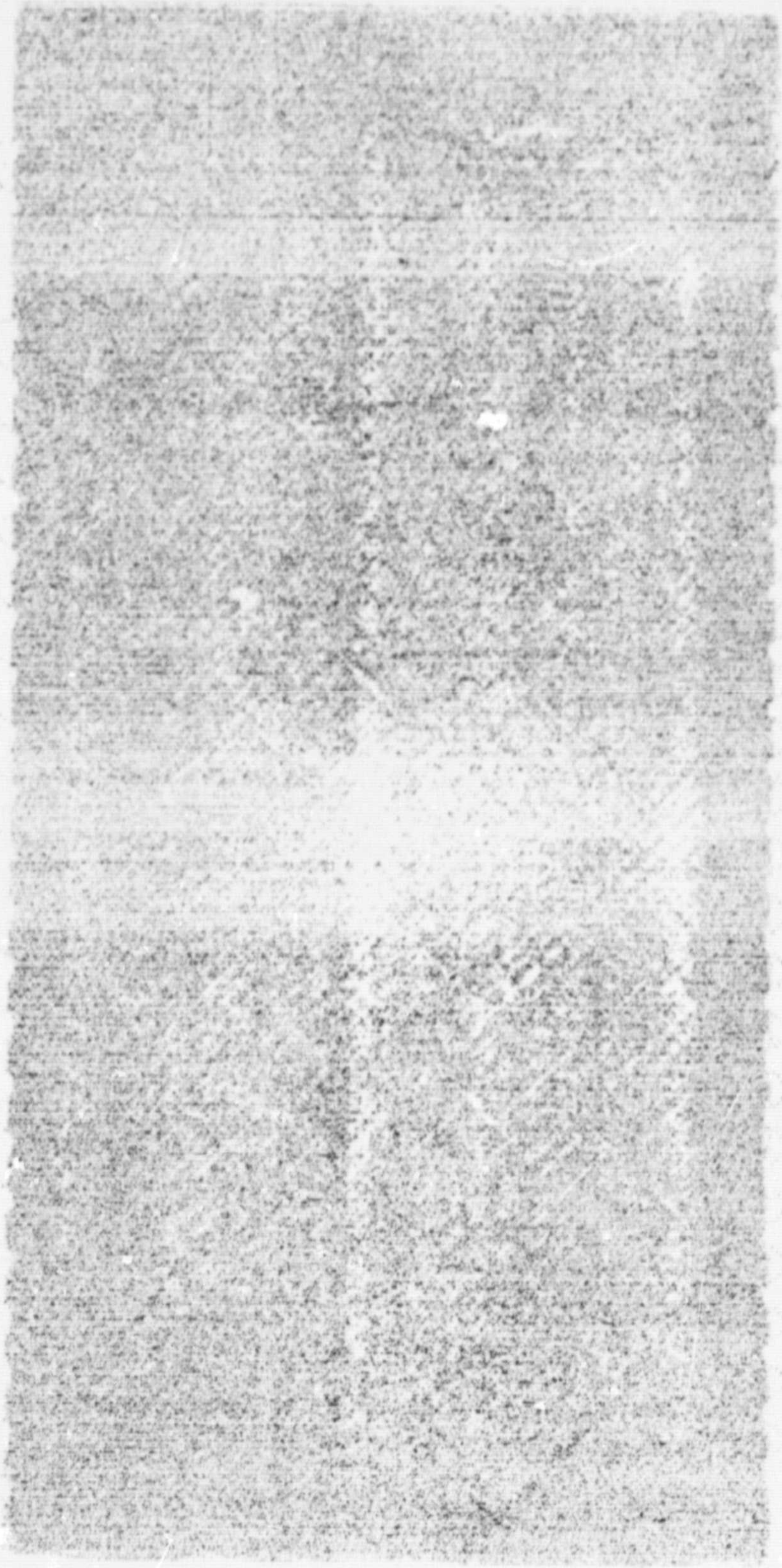

Figure 96. C-scan Laminate EX227, $(0,\pm45,90)_S$, 8 Plies

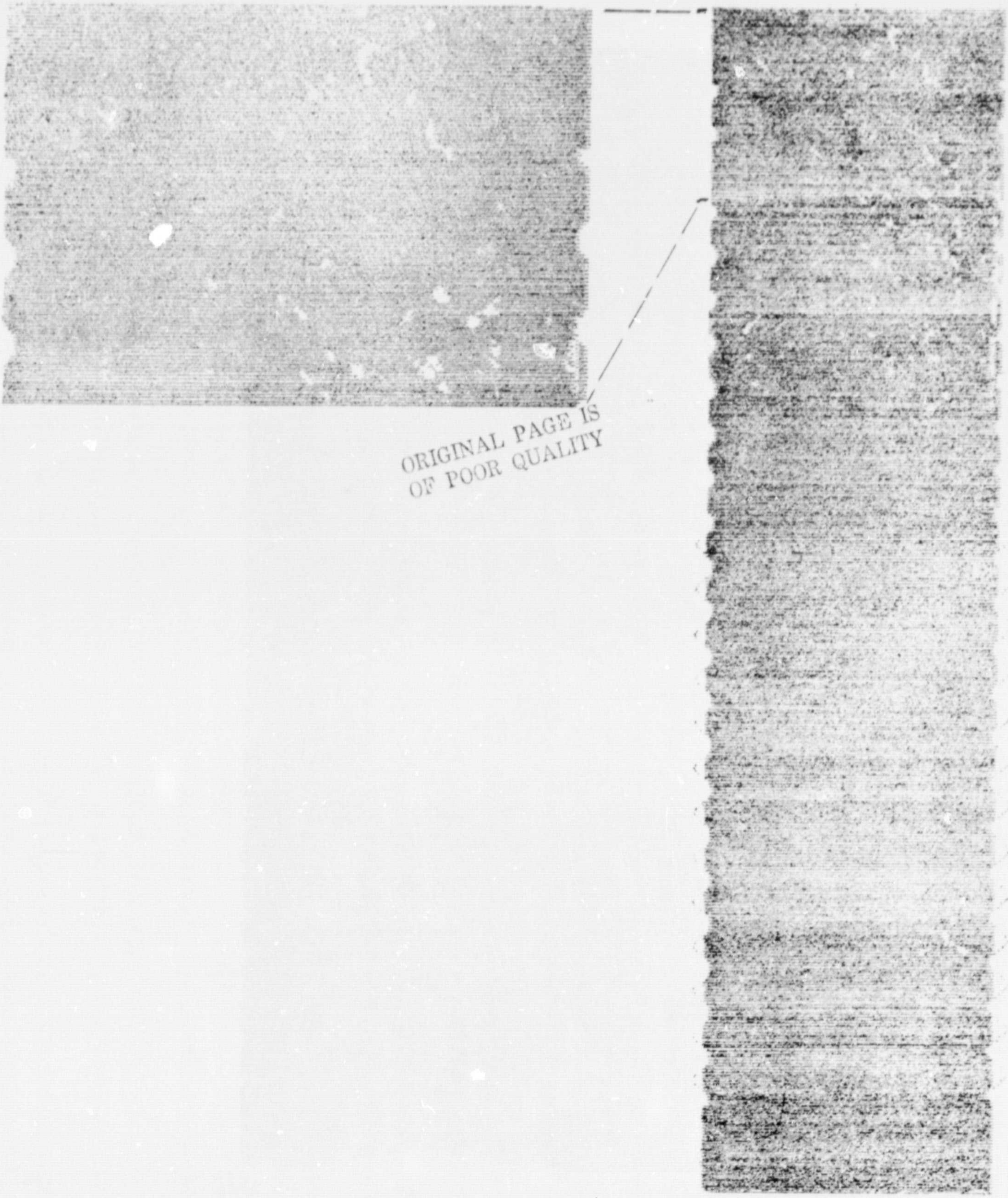

Figure 97. C-scan Laminate EX228, $(0,\pm45,90)_S$, 8 Plies

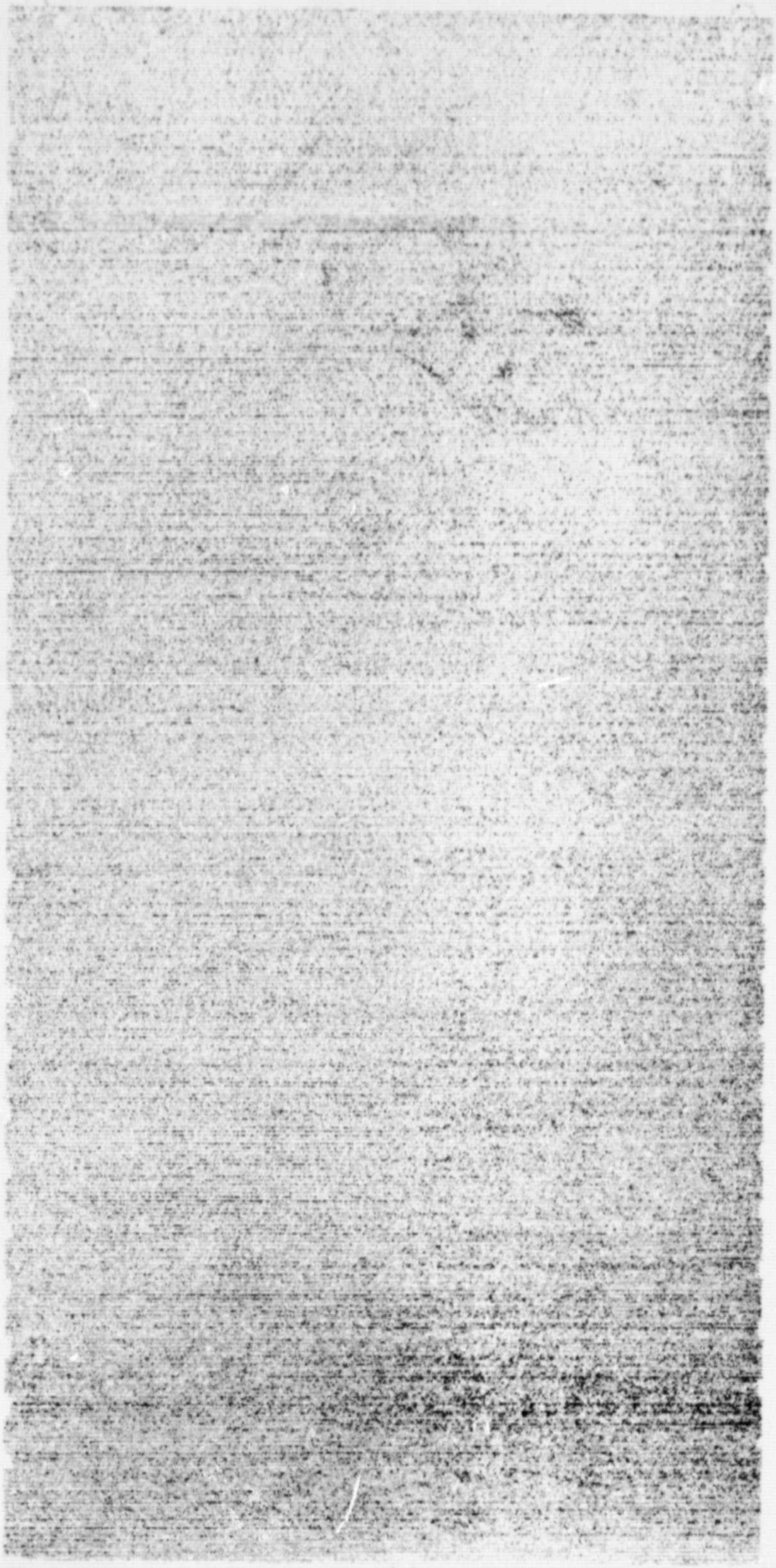

Figure 98. C-scan Laminate CL8C-14, $(0,\pm 45,90)_S$, 8 Plies

Figure 99. C-scan Laminate CL8C-18, $(0,\pm45,90)_S$, 8 Plies

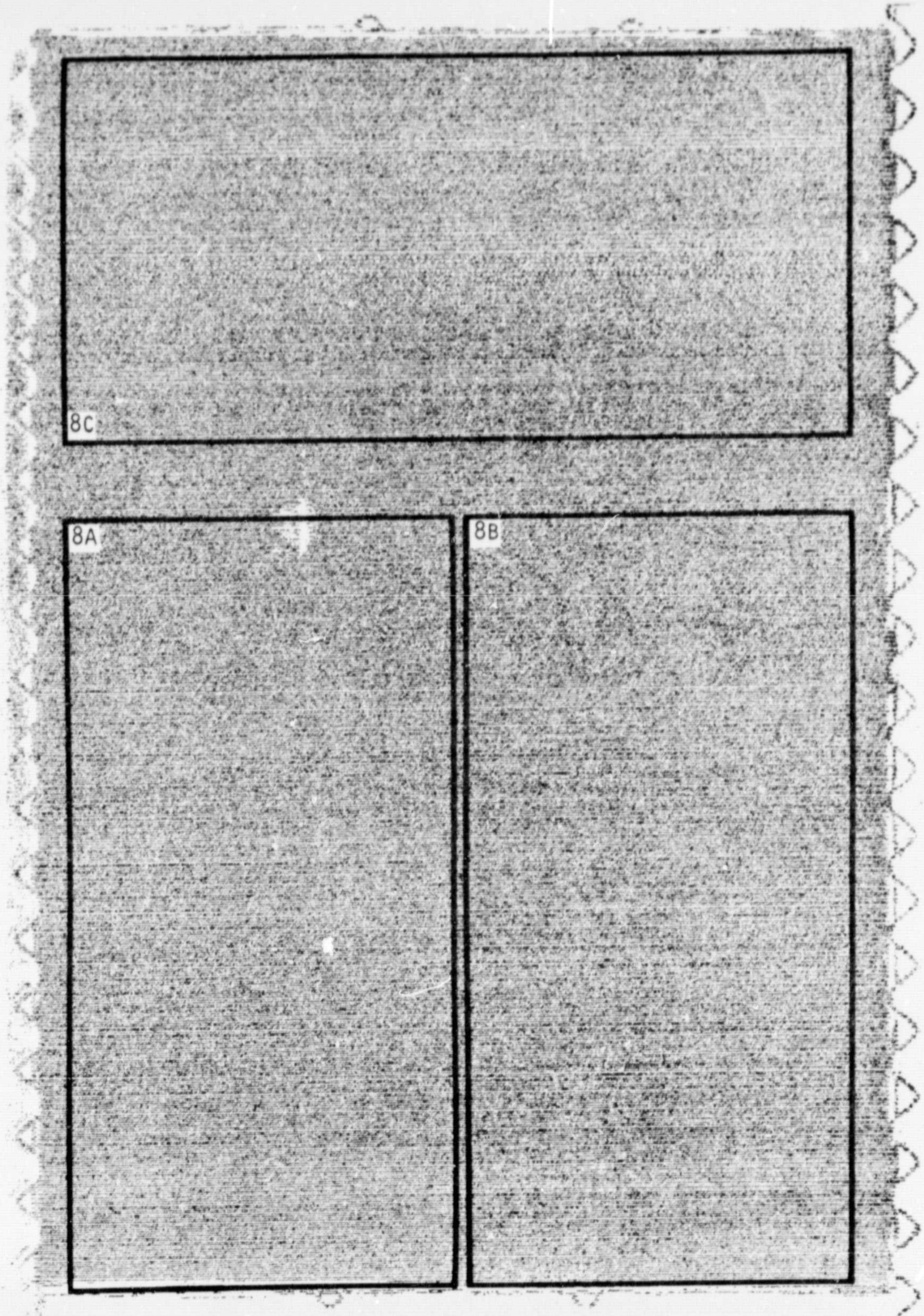

Figure 100. C-Scan Laminate Cl 12C-8, $(0,90)_t$, 12 Plies, Skin for Honeycomb Panels

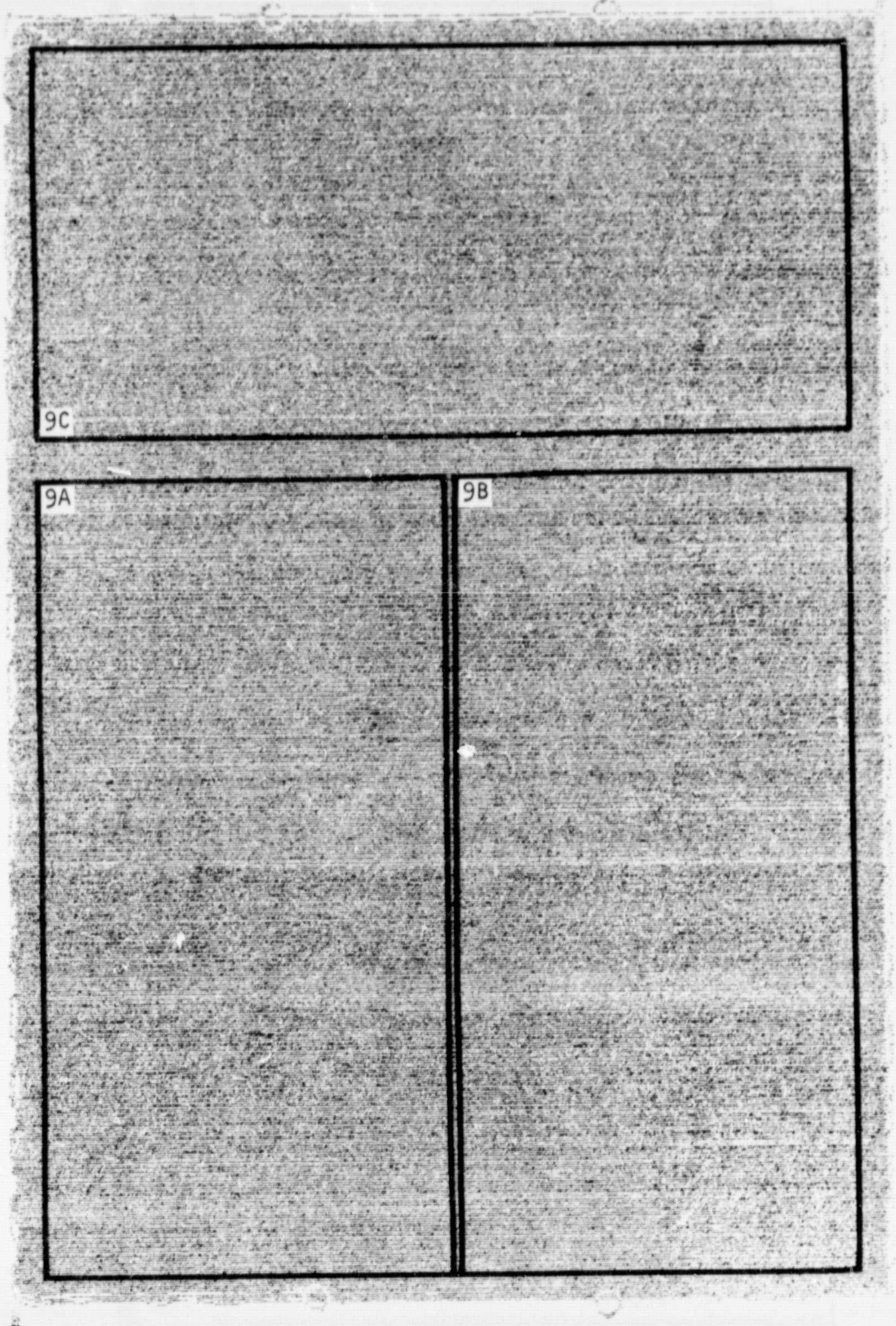

Figure 101. C-Scan Laminate CL 12C-9, $(0,90)_t$, 12 Plies, Skin for Honeycomb Panels

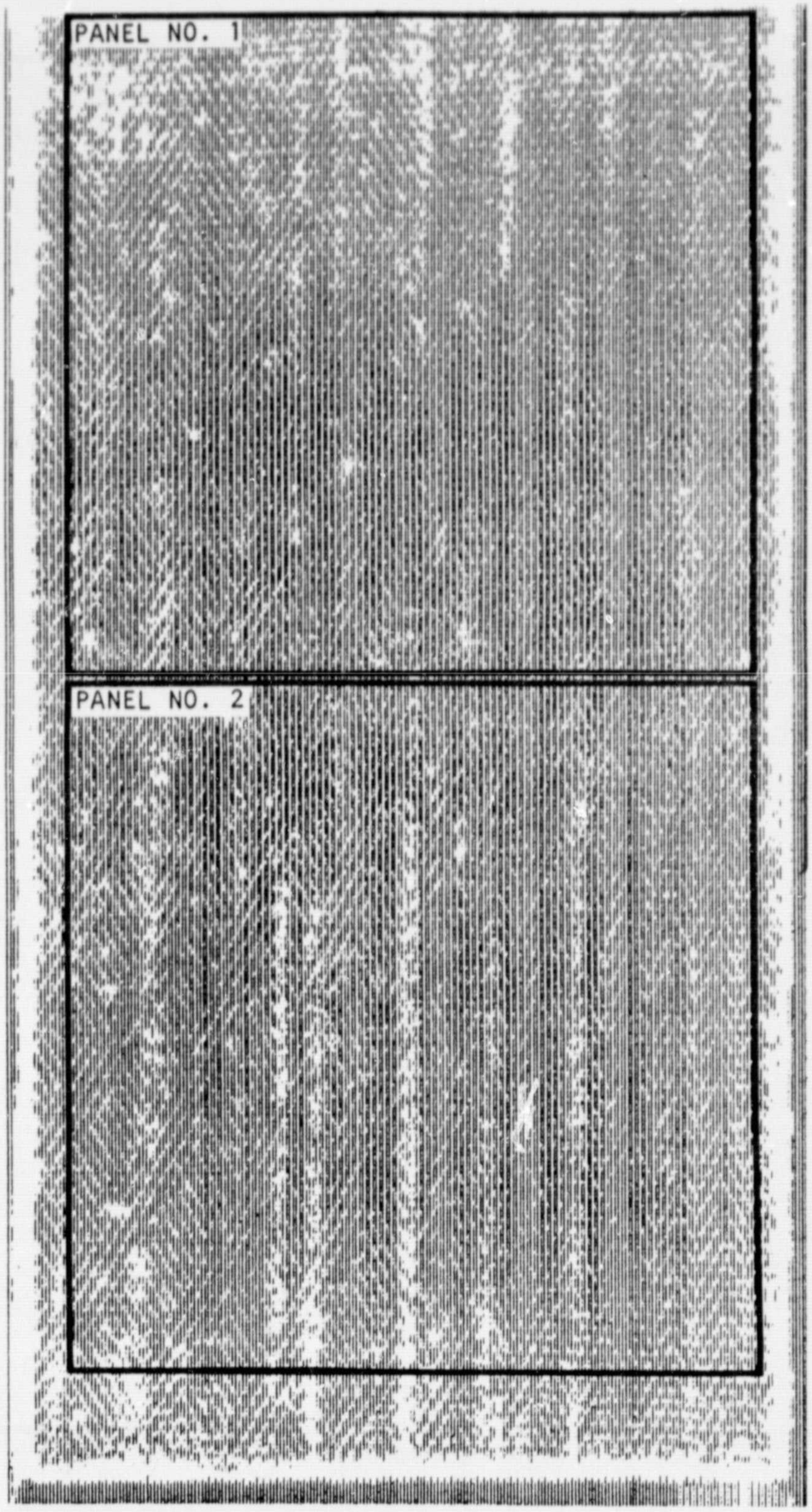

Figure 102. C-Scan Honeycomb Panel 8A with Location of 25.4 X 25.4-cm Panels No. 1 and No. 2

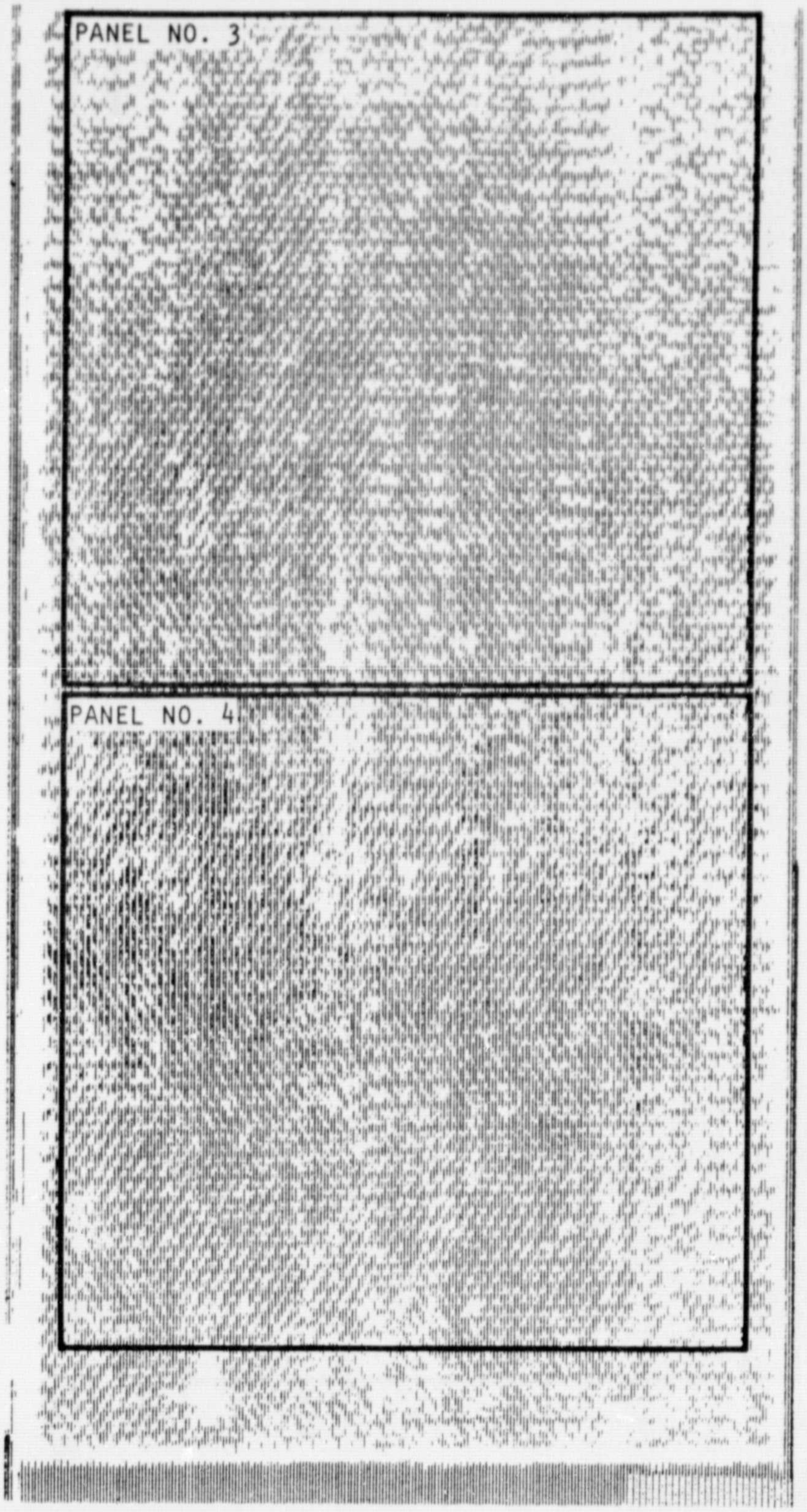

Figure 103. C-Scan Honeycomb Panel 9A with Location of 25.4 X 25.4-cm Panels No. 3 and No. 4

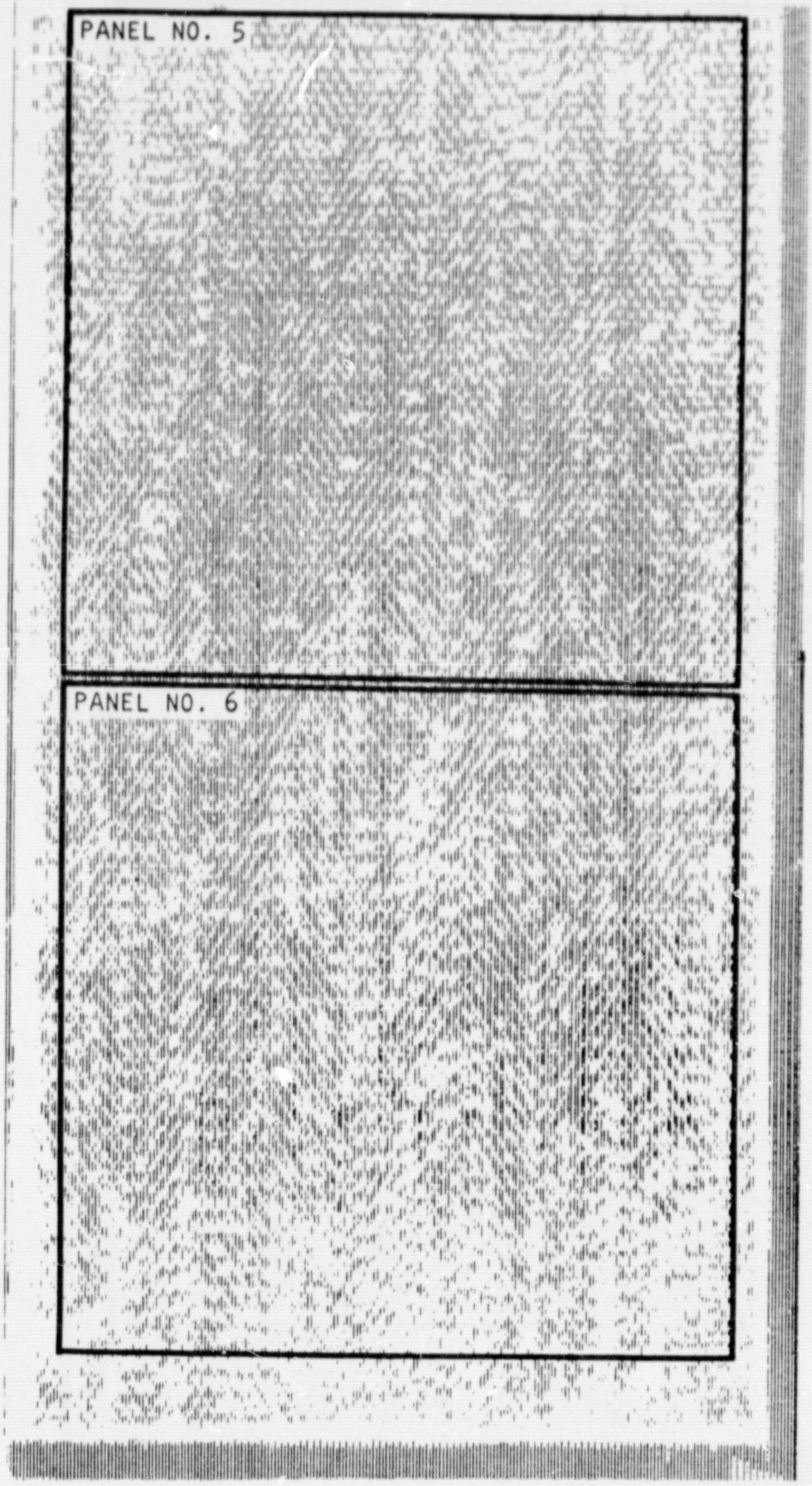

Figure 104. C-Scan Honeycomb Panel 9C with Location of 25.4 X 25.4-cm Panels No. 5 and No. 6

TABLE 1. HEXCEL LARC-160 INTERMEDIATE ESTER BATCHES EXAMINED BY HPLC

SAMPLE	HEXCEL DESIGNATION	ESTER VARIATIONS
	(Standard Production Batches)	
A	22367 544 Cut 2	Std Composition & Processing
B	22361 544 Cut 4	Std Composition & Processing
C	22408 545 Cut 1	Std Composition & Processing
D	22746 545 Cut 1	Std Composition & Processing
E	22746 545 Cut 2	Std Composition & Processing
F	22746 545 Cut 3	Std Composition & Processing
G	23245 545 Cut 2	Std Composition & Processing
H	23245 545 Cut 5	Std Composition & Processing
	(Variables Study Batches)	
1	22943	Std Composition & Processing
2	22944	Std Composition & Processing
3	22945	Std Composition & Processing
4	22946	Std Composition & Processing
5	22947	Std Composition & Processing
6	22948	Std Composition & Processing
1A	22990	Std Composition & Processing
2A	22991	Std Composition & Processing
7	22949	+5% NA, Standard Processing
8	22950	+5% BTDA, Standard Processing
9	22951	-5% NA, Standard Processing
10	22952	-5% BTDA, Standard Processing
11	22953	Std Composition & Processing
12	22954	Std Composition & Processing
13	22955	Std Composition & Processing
14	23107	Std Composition & Processing
15	23236	Std Composition & Processing
*16A	23357	Std Composition & Processing
16	23357	Std Composition & Processing

* Initial Control Batch for Variables Program. Insufficient resin to prepreg necessitated new Control Batch (16) to be prepared.

Table 2. Prepreg Physical Properties, Hexcel Batches 23328 and 23431

Prepreg Property	Tape Zone (2)	Batch No./Roll No.						Requirement
		23328				23451		
		R3		R4		R4		
		L&T	HEX	L&T	HEX	L&T	HEX	
Resin/ volatile pickup (%)	1	48.3		42.4		51.0		
	2	47.1	48.7	46.1	48.7	46.1	46.2	42-48
	3	43.3		49.7		48.4		
	Avg	46.2		46.1		48.5		
Volatiles (%)	1	13.7		11.1		10.6		
	2	13.2	14.8	12.1	14.9	11.1	13.1	9-15
	3	11.9		12.5		11.9		
	Avg	12.9		11.9		11.2		
Resin Solids (%)	1	37.9		35.2		45.1		
	2	39.1	39.7	38.7	39.7	39.4	38.1	34.41
	3	35.6		42.6		41.5		
	Avg	37.5		38.8		42.0		
Fiber Areal Wt (grams/m^2	1	147		160		137		
	2	151	150	147	151	146	149	148-156
	3	153		139		117		
	Avg	150		149		133		
Calc. Ply thickness (mils)	1	5.51		6.00		5.12		
	2	5.66	5.62	5.53	5.66	5.49	5.59	5.55-5.85
	3	5.74		5.20		5.33		
		5.64		5.58		5.31		

(1) Physical properties tests and calculations per Appendix A of 1st Quarterly Report.

(2) Tape Zone Physical Properties Samples

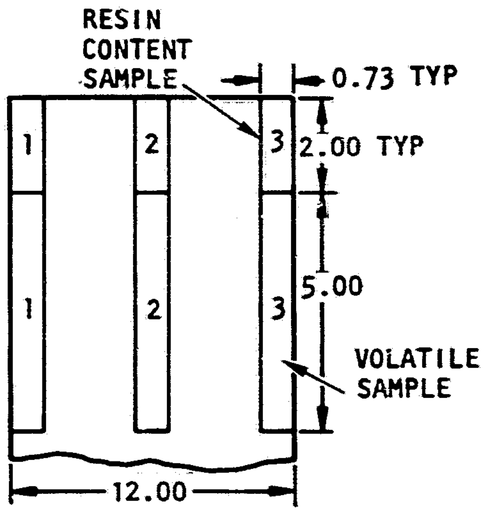

Table 3. Prepreg and Composite Physical and Mechanical Properties

Properties / Panel No./No. Plies	Target (5) Property		EX223		EX224		EX254	
Prepreg History								
1. Prepreg batch/No. Plies	--		23328/14		23328/11		23451/11	
Prepreg Physical Properties								
1. Fiber areal weight (grams/m²)	152 + 4		150		150		133	
2. Calc thick./ply, 60% fiber vol, mm (mils)	0.134-0.147 (5.5-5.8)		0.142 (5.62)		0.142 (5.62)		0.135 (5.31)	
3. Resin solids content (%)	38.0 + 3		39.7		39.7		42.0	
4. Volatile content (%)	10-15		14.8		14.8		11.2	
Composite Physical Properties(1)								
1. Specific gravity (grams/cc)	1.561-1.579		1.622		1.599		1.601	
2. Resin weight content (%)	35.0-31.3		28.2		28.9		29.8	
3. Fiber volume (%)	58-62		65.7		64.2		63.5	
4. Void volume (%)	<2		-0.85		-0.22		-0.19	
5. Thickness mm (mils)			1.52-1.63 (60-64)		1.27-1.35 (50-53)		1.42-1.60 (56-63)	
6. Thickness/Ply, mm (mils)			0.109-0.117 (4.3-4.6)		0.114-0.122 (4.5-4.8)		0.129-0.144 (5.1-5.7)	
7. Barcol hardness (ASTM 2583)	>70		72-76		72-75		74-76	
8. Weight loss in postcure (%)	<1		0.18		0.15		0.16	
9. TMA-Tg C, (F)							-	
Postcured 4 hrs at 316 C (600 F)	>340 (644)		346 (655)		351 (664)			
0. C-Scan ultra sould transmission (%) (3)								
Cured	>95		100		100		100	
Postcured 4 hrs at 316 C (600 F)	>95		100		100		100	
Composite Mechanical Properties(4)			MN/m²	(Ksi)	MN/m²	(Ksi)	MN/m²	(Ksi)
1. Flexural strength	MN/m²	(Ksi)						
RT				(243)		(271)		(281)
				(232)		(271)		-
				(264)		(273)		(251)
Avg			1695	(246)	1798	(261)	1833	(266)
Avg normalized strength, 60% F/V	>1571	(>136)	1548	(225)	1681	(243)	(1732)	(251)
316 C (60 F)				(152)		(172)		(158)
				(166)		(158)		(167)
				(154)		(184)		(173)
Avg			1082	(157)	1178	(171)	1144	166
Avg normalized strength, 60% F/V	>942	(>136)	988	(143)	1101	(160)	(1081)	(157)
2. Flexural modulus	GN/m²	(Msi)	GN/m²	(Msi)	GN/m²	(Msi)	GN/m²	(Msi)
RT						(1.50)		
				(17.7)		(19.7)		
				(17.9)		(19.9)		19.2
				(20.6)		(19.1)		-
								18.7
Avg			129	(18.7)	130	(18.9)	131	19.0
Avg normalized modulus, 60% F/V	>124	(>18)	118	(17.0)	122	(17.7)	124	(18.0)
316 C (600 F)				(16.7)		(20.1)		(16.2)
				(18.3)		(19.7)		(18.4)
				(19.0)		(19.9)		(17.9)
Avg			124	(18.0)	137	(19.9)	121	(17.6)
Avg normalized modulus, 60% F/V	>124	(>18)	113	(16.4)	128	(18.6)	115	(16.6)
3. Short beam shear strength	MN/m²m	(Ksi)	MN/m²	(Ksi)	MN/m²	(Ksi)	MN/m²	(Ksi)
RT	>103	(>15)						
				(14.7)		(17.4)		(17.0)
				(14.7)		(17.4)		(17.6)
				(12.8)		(17.1)		(17.1)
Avg			97	(14.1)	119	(17.3)	1221	(17.2)
316 C (600 F)	>48	(>7)						
				(6.7)		(8.3)		(7.5)
				(6.7)		(7.4)		(6.6)
				(6.7)		(7.7)		(5.8)
Avg			46	(6.7)	54	(7.8)	45.5	(6.6)

Table 4. Test Matrix Effect of Resin Formulation/Process Variables

PREPREG BATCH 1.35 KG (3 LB) EA	FORMULATION VARIABLES		PROCESS VARIABLES		ANALYSES							
	CONC. AP-22	CONC. ANHYDRIDES	COOK TIME	REFLUX TIME	NA	BTDA	AP-22	INT. ESTER	RESIN	PREPREG EXTRACT	LAM	PANEL NO.
STANDARD					✓	✓	✓	✓	✓	✓	✓	
1	+2%	STD	STD	STD	✓	✓	✓	✓	✓	✓	✓	EX217
2	-2%							✓	✓	✓	✓	EX218
3	+5%							✓	✓	✓	✓	EX205
4	+5%							✓	✓	✓	✓	EX206
5	+10%							✓	✓	✓	✓	EX207
6	-10%	STD	STD	STD				✓	✓	✓	✓	EX208
7	STD	NA (+5%) BTDA (STD)	STD	STD				✓	✓	✓	✓	EX209
8		NA (-5%) BTDA (STD)						✓	✓	✓	✓	EX210
9		NA (STD) BTDA (+5%)						✓	✓	✓	✓	EX211
10	STD	NA (STD) BTDA (-5%)	STD	STD				✓	✓	✓	✓	EX212
11	STD	STD	2 HRS AT 70C	STD				✓	✓	✓	✓	EX213
12	STD	STD	2 HRS AT 60C	STD				✓	✓	✓	✓	EX214
13	STD	STD	STD	6 HR				✓	✓	✓	✓	EX215
14	ANCAMINE STD	STD	STD	STD				✓	✓	✓	✓	EX216
15	TONAX STD	STD	STD	STD				✓	✓	✓	✓	EX219

Table 5. Prepreg Physical Properties, LARC-160 Resin Stoichiometry Variable Program

Prepreg Property (1)	Tape Zone (3)	Prepreg/Resin Batch Numbers															
		22945/3		22946/4		22947/5		22948/6		22949/7		22950/8		22951/9		22952/10	
		L&T	HEX	L&T	HEX	L&T	HEX	L&T	HEX	L&T	HEX	L&T	HEX	L&T	HEX	L&T	HEX
Resin/ volatile pickup (%)	1	49.4		49.1		49.6		47.9		52.2		57.8		50.8		55.4	
	2	47.4		52.8		47.6		44.4		42.7		46.5		48.3		46.3	
	3	52.5		46.8		52.4		46.7		50.3		46.0		52.3		50.0	
	Avg	49.8	49.2	49.6	44.0	49.9	45.2	46.3	47.1	48.4	-	50.1	-	50.5	-	50.6	-
Resin Solids (%)	1	40.8		39.3		41.0		38.2		44.0		50.0		44.4		46.7	
	2	41.5		44.7		43.7		35.0		34.5		38.5		40.6		38.4	
	3	43.9		37.4		43.7		37.5		41.5		37.6		44.0		41.2	
	Avg	42.1	34.6	40.4	35.2	42.8	36.3	36.9	39.0	40.0	42.8	42.0	33.0	43.0	38.2	42.1	38.4
Volatiles (%)	1	14.5		16.2		14.5		15.7		14.6		16.1		14.9		16.5	
	2	13.2		14.6		13.4		15.0		12.6		12.9		13.0		12.9	
	3	15.3		14.9		15.5		14.7		15.0		13.1		15.1		14.9	
	Avg	14.3	13.4	15.2	13.1	14.5	14.1	15.1	14.0	14.1	13.5	14.0	14.6	14.3	14.0	14.8	14.8
Fiber Areal Wt (grams/m^2)	1	135		127		128		132		120		100		115		105	
	2	137		120		137		136		126		133		122		135	
	3	120		135		118		129		121		134		112		119	
	Avg	131	130	127	136	126	136	132	136	122	123	122	132	116	129	120	130
Calc. Ply (2) thickness (mils)	1	5.1		4.8		4.8		4.9		4.5		3.7		4.3		3.9	
	2	5.2		4.5		5.2		5.1		4.8		5.0		4.6		5.0	
	3	4.6		5.1		4.4		4.8		4.5		5.0		4.2		4.4	
	Avg	5.0	4.9	4.8	5.1	4.8	5.1	4.9	5.1	4.6	4.6	4.6	4.9	4.4	4.8	4.4	4.9

(1) Prepreg requirements: Resin solids (%): 37 ± 3; Volatiles (%): 12 ± 3; Fiber Areal weight (grams/m^2): 134 ± 4; Calculated ply thickness mm (mils): 0.124 - 0.132 (4.9 - 5.2). Physical properties test and calculations per Appendix A of 1st Quarterly Report.

(2) Calculated thickness based on a 60% fiber volume laminate.

(3) Tape Zone Physical Properties Samples

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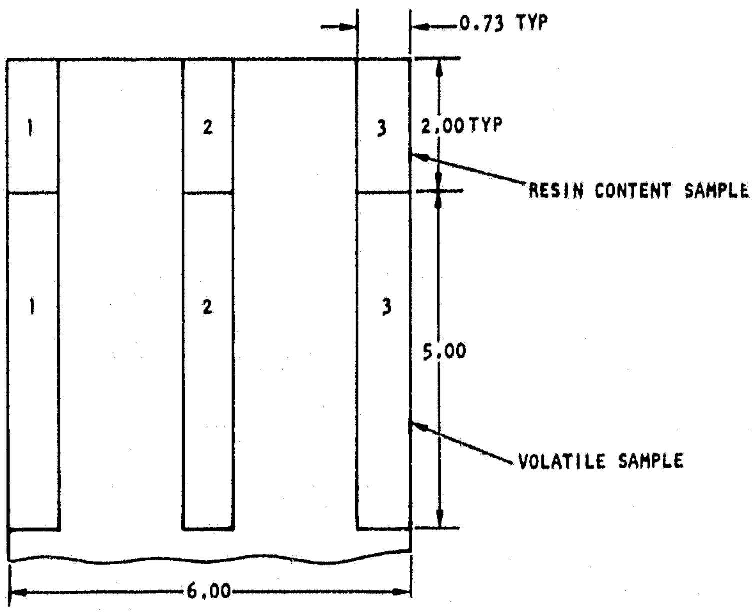

Table 5. Prepreg Physical Properties, LARC-160 Resin Stoichiometry Variable Program (Cont)

Prepreg[(1)] Property	Tape Zone (3)	Prepreg/Resin Batch Number													
		22953/11		22954/12		22955/13		23107/2		22990/14		22991/1		23236/15	
		L&T	HEX	L&T	HEX	L&T	HEX	L&T	HEX	L&T	HEX	L&T	HEX	L&T	HEX
Resin/volatile pickup (%)	1	48.4		46.6		57.9		48.9		63.3		47.5		49.3	
	2	57.3		36.6		44.5		46.8		40.3		42.4		50.1	
	3	53.2		61.1		43.8		56.8		46.8		60.8		39.8	
	Avg	53.0	-	48.1	-	48.7	-	50.8	50.0	50.1	-	50.2	-	46.4	-
Resin Solids (%)	1	41.9		38.7		49.1		41.0		58.8		38.8		41.0	
	2	50.9		29.3		35.9		39.2		31.7		32.8		42.2	
	3	45.6		53.4		34.9		48.9		38.6		51.9		33.6	
	Avg	46.1	43.0	40.5	38.4	40.0	39.3	43.0	38.4	43.0	40.5	41.2	40.4	38.9	37.0
Volatiles (%)	1	11.2		12.9		17.2		13.3		10.8		14.2		13.0	
	2	13.0		10.3		13.5		12.4		12.6		14.3		12.7	
	3	14.0		15.5		13.6		15.6		13.3		18.4		9.3	
	Avg	12.7	14.9	12.9	13.6	14.8	13.5	13.8	11.8	12.2	12.9	15.6	13.7	11.7	-
Fiber Areal Wt (grams/m^2)	1	126		123		99		125		925		133		125	
	2	102		149		130		133		152		152		120	
	3	118		90		133		96		134		97		153	
	Avg	115	125	120	129	121	131	118	132	126	136	127	132	133	-
Calc. Ply[(2)] thickness (mils)	1	4.7		4.6		3.7		4.7		3.5		5.0		4.7	
	2	3.8		5.6		5.2		4.9		5.7		5.7		4.5	
	3	4.4		3.4		5.0		3.5		5.0		3.6		5.7	
	Avg	4.3	4.7	4.5	4.8	4.6	4.9	4.4	4.9	4.7	5.1	4.8	4.9	5.0	-

(1) Prepreg requirements: Resin solids (%): 37 ± 3; Volatiles (%): 12 ± 3; Fiber Areal weight (grams/m^2): 134 ± 4; Calculated ply thickness mm (mils): 0.24 - 0.132 (4.9 - 5.2). Physical properties tests and calculations per Appendix A of 1st Quarterly Report.

(2) Calculated thickness based on a 60% fiber volume laminate.

(3) Tape Zone Physical Properties Samples

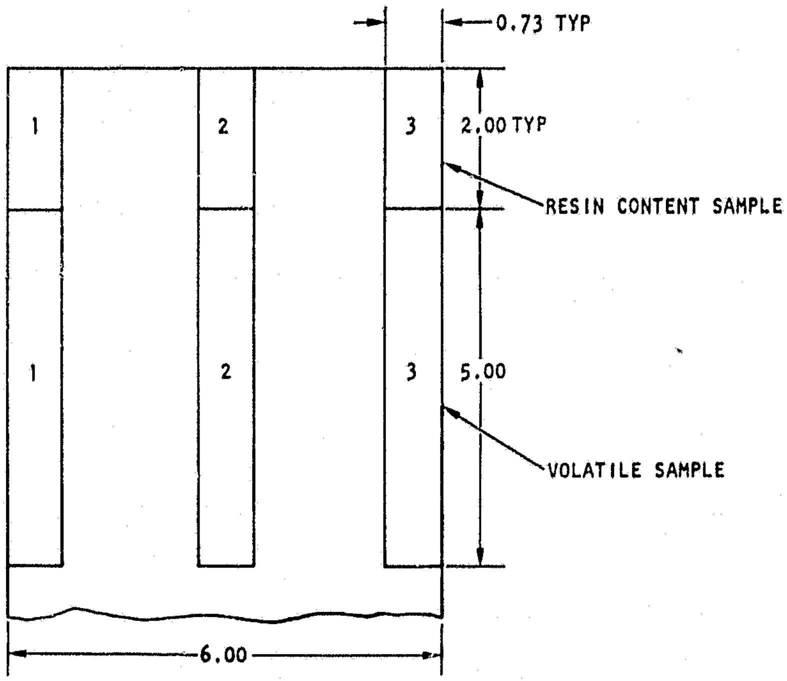

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Table 6. Prepreg and Composite Physical, Short Beam Shear and Flexural Properties, LARC-160 Resin Stoichiometry and Process Variable Program

Properties / Laminate No.	Target(2) Property	EX217		EX218		EX205		EX206		EX207	
Resin/Process Variable											
1. Resin Run No.	—	1		2		3		4		5	
2. Concentration AP22	—	+2%		-2%		+5%		-5%		+10%	
3. Concentration Anhydrides	—	STD		STD		STD		STD		STD	
4. Cook time	—	STD		STD		STD		STD		STD	
5. Reflux time	—	STD		STD		STD		STD		STD	
Processing Parameters(1)											
1. Type of bleeder/No. Plies(6)	—	120/2T & 1B		120/*T & 1B		120/1T & B		120/1T & B		120/1T & B	
Prepreg Physical Properties											
1. Prepreg batch	234+4	22991		23107		22945		22946		22947	
2. Fiber areal weight (grams/m²)	0.131-0.124	127		118		131		127		126	
3. Calc. Thick./ply, 60% fiber vol, mm (mils)	(5.2-4.9)	0.122 (4.8)		0.112 (4.4)		0.127 (5.0)		0.122 (4.8)		0.122 (4.8)	
4. Resin solids content (%) as is	38.0 ± 3	41.2		43.0		42.1		40.4		42.8	
5. Resin solids content staged (%)(5)	32-36	32.2		31.7		28.4		30.5		34.4	
6. Volatile content as is (%)	9-14	15.6		13.8		14.3		15.2		14.5	
7. Volatile content staged (%)(5)	<2	1.13		1.11		3.04		2.65		1.97	
Composite Physical Properties(1)											
1. Specific gravity (grams/cc)	1.573-1.591	1.59		1.595		1.59		1.60		1.56	
2. Resin weight content (%)	31.05-34.71	34.0		29.1		30.8		28.2		31.8	
3. Fiber volume (%)	58-62	59.3		63.9		62.2		64.9		60.2	
4. Void volume (%)	<2	-0.18		0.97		0.74		0.92		2.3	
5. Thickness mm (mils)	—	1.42-1.60 (56-63)		1.45-1.65 (57-65)		1.16-1.37 (46-54)		1.45-1.55 (57-61)		1.63-1.75 (64-69)	
6. Thickness/ply, mm (mils)	—	0.102-0.114 (4.[illegible]-4.5)		0.104-0.117 (4.1-4.6)		0.084-0.097 ([illegible])		[illegible]		0.117-0.124 (4.6-4.9	
7. Barcol hardness (ASTM 2583)	>70	72-75		72-74		72-76		74-76		64-68	
8. Weight loss in postcure (%)	<1	0.23		0.23		0.27		0.24		0.24	
9. Weight loss after 125 hrs at 316 C (600 F) (%)	<3	1.48		1.40		1.58		1.46		1.57	
10. TMA-Tg C, (F) postcured 4 hrs at 316 C (600 F)	>340 (644)	356 (673)		340 (644)		347 (357)		337 (639)		367 (693)	
11. C-Scan ultra sound transmission (%)(3)											
Cured	>95	100		100		100		100		100	
Postcured 4 hrs at 316 C (600 F)	>95	100		100		100		100		100	
Composite Mechanical Properties(4)	MN/m² (Ksi)	MN/m²	(Ksi)	MN/m²	(Ksi)	MN/m²	(Ksi)	MN/m²	(Ksi)	MN/m²	(Ksi)
1. Flexural strength RT			(253)		(268)		(254)		(273)		(222)
			(278)		(254)		(267)		(250)		(228)
			(269)		(252)		(267)		(274)		(216)
		1840	(267)	1778	(258)	1812	(263)	1833	(266)	1530	(222)
Avg normalized strength, 60% F/V	>1571 (>228)	1861	(270)	1669	(242)	1750	(254)	1695	(246)	1530	(222)
316 C (600 F)			(161)		(132)		(160)		(155)		(131)
			(170)		(132)		(149)		(138)		(136)
			(159)		(134)		(169)		(132)		(142)
Avg		1033	(150)	916	(133)	1096	(159)	978	(142)	937	(136)
Avg normalized strength, 60% F/V	>937 ([illegible])	1046	(152)	860	(125)	1057	(153)	900	131	(937)	(136)
2. Flexural modulus RT	GN/m² (M[illegible]	GN/m²	(Msi)	GN/m²	(Msi)	GN/m²	(Msi)	GN/m²	(Msi)	GN/m²	(Msi)
			(19.7)		(19.3)		(19.6)		(21.0)		(18.0)
			(17.3)		(19.3)		(19.9)		(18.4)		(25.2)
			(18.5)		(19.7)		(18.7)		(19.4)		(17.3)
Avg		127	(18.5)	134	(19.4)	134	(19.4)	135	(19.6)	140	(20.2)
Avg normalized modulus, 60% F/V	>124 (>18)	129	(18.7)	126	(18.2)	129	(18.7)	124	18.0	140	(20.2)
316 C (600 F)			(20.5)		(17.4)		(19.2)		(19.1)		(17.8)
			(16.5)		(16.9)		(18.1)		(18.1)		(17.4)
			(20.3)		(18.5)		(19.2)		(15.2)		(16.9)
Avg		132	(19.1)	916	(17.6)	130	(18.8)	121	(17.5)	119	(17.4)
Avg normalized modulus, 60% F/V	>124 (>18)	133	(19.3)	114	(16.5)	125	(18.1)	111	(16.1)	119	(17.4)
3. Short beam shear strength RT	MN/m² (Ksi) >103 (>15)	MN/m²	(Ksi)	MN/m²	(Ksi)	MN/m²	(Ksi)	MN/m²	(Ksi)	MN/m²	(Ksi)
			(17.1)		(16.2)		(16.4)		(16.4)		(11.8)
			(17.9)		(16.2)		(17.1)		(18.4)		(12.5)
			(17.9)		(16.6)		(18.1)		(17.6)		(13.1)
Avg		121	(17.6)	112	(16.3)	118	(17.2)	120	(17.5)	86	(12.5)
316 C (600 F)	>48 (>7)		(8.9)		(6.5)		(8.4)		(6.1)		(8.8)
			(8.2)		(6.4)		(7.3)		(6.2)		(8.6)
			(6.9)		(5.9)		(7.4)		(5.8)		(8.5)
Avg		55	(8.0)	43	(6.3)	53	(7.7)	41	(6.0)	59	(8.6)

(1) The preimidizing 2 stage cure cycle and tooling specified in the 5th Quarterly Report was employed in fabrication of 14 ply unidirectional laminates 17.78 x 1[illegible].59 Cm (7.7 x 5.5 inches). Laminates were postcured at 316 C (600 F) for 4 hours, freestanding in an air circulating oven. Prepreg and composite physical properties were calculated per Appendix A of the First Quarterly Report.
(2) Target property values are based on Celion fiber minimum properties of 2618 MN/m², (380 Ksi) tensile strength and 234 GN/m², (34 Msi) tensile modulus using the rule of mixtures, 60% composite fiber volume. Target 316 C (600 F) strength properties are based on a 60% retention of room values.
(3) NDE ultrasonic through transmission tests were performed using the NASA-LaRC established "A" sensitivity standards.
(4) Specimens were tested after stabilizing at 316 C (600 F) for 10 minutes.
(5) Volatiles and resin solids content determined on portion of stacked laminate.
(6) T = number of bleeder plies on top surface of laminate; B = number of bleeder plies on bottom surface.

Table 6. Prepreg and Composite Physical, Short Beam Shear and Flexural Properties, LARC-160 Resin Stoichiometry and Process Variable Program (Cont)

Properties / Laminate No.	Target[2] Property	EX208	EX209	EX210	EX211	EX212
Resin/Process Variable						
1. Resin Run No.		6	7	8	9	10
2. Concentration AP22		-10%	STD	STD	STD	STD
3. Concentration anhydrides		STD	NA(+5%), BTDA(STD)	NA(-5%), BTDA(STD)	NA(STD), BTDA(+5%)	NA(STD), BTDA(-5%)
4. Cook time		STD	STD	STD	STD	STD
5. Reflux time		STD	STD	STD	STD	STD
Processing Parameters[1]						
1. Type of bleeder/no. plies[6]	—	120/2T & 1B	181/1T & 1B	120/1B only	120/2T & 1B	120/2T & 1B
Prepreg Physical Properties						
1. Prepreg batch	134+4	22948	22949	22950	22951	22952
2. Fiber areal weight (grams/m²)	0.131-0.124	132	122	122	116	120
3. Calc thick/ply, 60% fiber vol, mm (mils)	(5.2-4.9)	0.124 (4.9)	0.117 (4.6)	0.117 (4.6)	0.112 (4.4)	0.112 (4.4)
4. Resin solids content (%) as is	38.0 +3	36.9	40.0	42.0	43.0	42.1
5. Resin solids content staged (%)[5]	32-36	30.7	30.3	35.7	30.8	28.3
6. Volatile content as is (%)	9-14	15.1	14.1	14.0	14.3	14.8
7. Volatile content staged (%)	<2	2.92	2.09	2.79	1.58	1.34
Composite Physical Properties[1]						
1. Specific gravity (grams/cc)	1.573-1.591	1.62	1.60	1.57	1.59	1.58
2. Resin weight content (%)	31.05-34.71	25.0	28.8	33.3	30.7	31.1
3. Fiber volume (%)	58-62	68.6	64.2	59.2	67.2	61.5
4. Void volume (%)	<2	0.68	0.91	1.24	2.02	1.26
5. Thickness mm (mils)		1.45-1.62 (57-64)	1.55-1.75 (61-69)	1.37-1.55 (54-61)	1.32-1.55 (52-61)	1.47-1.57 (58-62)
6. Thickness/ply, mm (mils)		0.104-0.116 (4.1-4.6)	0.117-0.124 (4.4-4.9)	0.099-0.112 (3.9-4.4)	0.094-4.4 (3 [illegible]-4.35)	0.104-0.112 (4.1-4.4)
7. Barcol hardness (ASTM 2583)	>70	1.48	1.48	1.5	1.31	1.17
8. Weight loss in posture (%)	<1	0.24	0.22	0.25	0.2[illegible]	0.23
9. Weight loss after 125 hr at 316°C (600°F) (%)	<3	1.48	1.48	1.51	1.31	1.17
10. TMA-Tg C, (F) postcured 4 hr at 316°C (600°F)	>340 (644)	339 (642)	364 (687)	340 (644)	340 (644)	353 (667)
11. C-scan ultra sound transmission (%)[3]						
Cured	>95	100	100	99	100	100
Postcured 4 hr at 316°C (600°F)	>95	100	100	100	100	100
Composite Mechanical Properties[4]						
1. Flexural strength	MN/m² (Ksi)	MN/m² (Ksi)	MN/m² (Ksi)	MN/m² (Ksi)	MN/m² (Ksi)	MN/m² (Ksi)
RT		(305)	(232)	(333)	(296)	(248)
		(321)	(245)	(248)	(319)	(262)
		(274)	(233)	(270)	(283)	(260)
Avg		2067 (300)	1633 (237)	1950 (283)	2060 (299)	1770 (257)
Avg normalized strength, 60% F/V	>1571 (>228)	1808 (262)	1526 (221)	1976 (287)	1839 (267)	1728 (251)
316°C (600°F)		(144)	(144)	(167)	(180)	(168)
		(155)	(157)	(155)	(143)	(134)
		(148)	(140)	(159)	(160)	(147)
Avg		1027 (149)	1013 (147)	1102 (160)	1109 (161)	985 (143)
Avg normalized strength, 60% F/V	>937 (>136)	898 (130)	942 (137)	1113 (162)	987 (143)	956 (139)
2. Flexural modulus	GN/m² (Msi)	GN/m² (Msi)	GN/m² (Msi)	GN/m² (Msi)	MN/m² (Msi)	GN/m² (Msi)
RT		(20.0)	(18.2)	(20.4)	(19.1)	(18.4)
		(18.5)	(17.9)	(20.0)	(20.3)	(22.5)
		(19.1)	(18.0)	(22.5)	(19.1)	(18.7)
Avg		132 (19.2)	124 (18.0)	145 (21.0)	134 (19.5)	137 (19.9)
Avg normalized modulus, 60% F/V	>124 (>18)	115 (16.7)	115 (16.7)	146 (21.2)	119 (17.3)	133 (19.3)
316°C (600°F)		(16.8)	(17.4)	(19.4)	(20.4)	(18.2)
		(17.6)	(16.7)	(17.9)	(19.4)	(15.7)
		(18.4)	(17.5)	(18.3)	(18.4)	(17.8)
Avg		121 (17.6)	118 (17.2)	127 (18.5)	134 (19.4)	119 (17.2)
Avg normalized modulus, 60% F/V	>124 (>18)	106 (15.3)	110 (16.0)	129 (18.7)	119 (17.3)	115 (16.7)
3. Short beam shear strength	MN/m² (Ksi)	MN/m² (Ksi)	MN/m² (Ksi)	MN/m² (Ksi)	MN/m² (Ksi)	MN/m² (Ksi)
RT	>103 (>15)	(17.6)	(13.9)	(18.0)	(17.5)	(16.9)
		(17.8)	(16.3)	(17.2)	(16.3)	(16.6)
		(16.9)	(15.5)	(16.0)	(15.5)	(16.5)
Avg		120 (17.4)	105 (15.2)	118 (17.1)	113 (16.4)	115 (16.7)
316°C (600°F)	>48 (>7)	(8.1)	(8.6)	(7.0)	(8.4)	(8.5)
		(7.6)	(8.3)	(8.3)	(8.3)	(8.1)
		(7.9)	(7.9)	(8.5)	(8.5)	(8.4)
Avg		54 (7.9)	58 (8.3)	54 (7.9)	58 (8.4)	57 (8.3)

(1) The preimidizing 2 stage cure cycle and tooling specified in the Fifth Quarterly Report was employed in fabrication of 14 ply unidirectional laminates 17.78 x 13.59 cm (7.0 x 5.5 inches). Laminates were postcured at 316°C (600°F) for 4 hours, freestanding in an air circulating oven. Prepreg and composite physical properties were calculated per Appendix A of the First Quarterly Report.

(2) Target property values are based on Celion fiber minimum properties of 2618 MN/m², (380 ksi) tensile strength and 234 GN/m², (34 Msi) tensile modulus using the rule of mixtures, 60% composite fiber volume. Target 316°C (600°F) strength properties are based on a 60 percent retention of room values.

(3) NDE ultrasonic through transmission tests were performed using the NASA-LaRC established "A" sensitivity standards.

(4) Specimens were tested after stabilizing at 316°C (600°F) for 10 minutes.

(5) Volatiles and resin solids content determined on portion of stacked laminate.

(6) T = number of bleeder plies on top surface of laminate; B = number of bleeder plies on bottom surface.

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Table 6. Prepreg and Composite Physical, Short Beam Shear and Flexural Properties, LARC-160 Resin Stoichiometry and Process Variable Program (Cont)

Properties / Laminate No.	Target Property (2)	EX213		EX214		EX215		EX216		[illegible]	
Resin/Process Variable											
1. Resin run no.		11		12		13		14		15	
2. Concentration AP22		STD.		STD.		STD.		STD. Ancamine		STD. T[illegible]	
3. Concentration anhydrides		STD.		STD.		STD.		STD.		STD.	
4. Cook time		Extended		Intermediate		STD.		STD.		STD.	
5. Reflux time		STD.		STD.		6 hr.		STD.		STD.	
Processing Parameters (1)											
1. Type of bleeder/No. Plies (6)		181/1T & 1B		120/2T & 1B		120/2T & 1B		120/2T & 1B		120/1T & 1B	
Prepreg Physical Properties											
1. Prepreg batch	13444	22953		22954		22955		22990		23236	
2. Fiber areal weight (grams/m^2)	0.131-0.124	115		120		121		126		133	
3. Calc. Thick./ply, 60% fiber vol, mm (mils)	(5.2-4.9)	0.109 (4.3)		0.114 (4.5)		0.117 (4.6)		0.119 (4.7)		0.127 (5.0)	
4. Resin solids content (%) as is	38.0 ± 3	46.1		40.5		40.0		43.0		38.9	
5. Resin solids content staged (%)	32-36	37.9		33.9		30.3		31.9		-	
6. Volatile content as is (%)	9-14	12.7		12.9		14.8		12.0		11.7	
7. Volatile content staged (%) (5)	<2	1.62		1.36		1.64		1.39		-	
Composite Physical Properties (1)											
1. Specific gravity (grams/cc)	1.573-1.591	1.56		1.59		1.59		1.59		1.489	
2. Resin weight content (%)	31.05-34.71	36.0		30.5		31.6		29.5		32.7	
3. Fiber volume (%)	58-62	56.1		62.4		61.6		63.3		56.6	
4. Void volume (%)	<2	1.04		0.82		0.31		1.19		6.5	
5. Thickness mm (mils)		1.62-1.78 (64-70)		1.49-1.80 (59-71)		1.39-1.65 (55-65)		1.52-1.72 (60-68)		1.72-1.98 (68-78)	
6. Thickness/Ply, mm (mils)		0.113-0.127 (4.6-5.0)		0.106-0.129 (4.2-5.1)		0.099-0.147 (3.9-4.6)		0.109-0.124 (4.3-4.9)		0.124-0.142 (4.9-5.6)	
7. Barcol hardness (ASTM 2583)	>70	69-73		69-73		73-76		72-74		64-68	
8. Weight loss in postcure (%)	<1	0.27		0.21		0.26		0.25		0.23	
9. Weight loss after 125 hrs at 316 C (600 F) (%)	<3	1.73		1.45		1.34		1.57		2.12	
10. TMA-Tg C, (F) Postcured 4 hrs at 316 C (600 F)	>340 (644)	337 (639)		340 (644)		340 (644)		355 (671)		374 (705)	
11. C-Scan ultra sound transmission (%) (3)											
Cured	>95	100		100		100		60		0	
Postcured 4 hrs at 316 C (600 F)	>95	100		100		100		70		0	
Composite Mechanical Properties (4)		MN/m^2	(Ksi)	MN/m^2	(Ksi)	MN/m^2	(Ksi)	MN/m^2	(Ksi)	MN/m^2	(Ksi)
1. Flexural strength RT	MN/m^2 (Ksi)		(219) (243) (221)		(237) (225) (240)		(261) (239) (262)		(240) (229) (240)		(188) (180) (169)
Avg		1557	(227)	1612	(234)	1743	(254)	1626	(236)	1233	(179)
Avg normalized strength, 60% F/V	>1571 (>228)	1665	(242)	1550	(225)	1698	(246)	1541	(224)	1307	(190)
316 C (600F)			(120) (119) (151)		(146) (155) (145)		(156) (144) (156)		(147) (138) (145)		(121) (110) (125)
Avg		896	(130)	1027	(149)	1047	(152)	985	(143)	820	(119)
Avg normalized strength, 60% F/V	>937 (>136)	958	(139)	987	(143)	1020	(148)	934	(134)	869	(126)
2. Flexural modulus RT	GN/m^2 (Msi)	GN/m^2	(Msi) (17.7) (18.5) (18.3)	GN/m^2	(Msi) (20.0) (19.6) (20.3)	GN/m^2	(Msi) (20.0) (19.2) (18.2)	GN/m^2	(Msi) (18.2) (18.7) (18.7)	GN/m^2	(Msi) (15.6) (16.0) (15.1)
Avg		125	(18.2)	138	(20.0)	1316	19.1	127	(18.5)	107	(15.6)
Avg normalized modulus, 60% F/V	>124 (>18)	134	(19.5)	132	(19.2)	128	(18.6)	121	(17.5)	114	(16.5)
316 C (600 F)			(15.7) (15.5) (17.7)		(18.3) (19.2) (17.8)		(19.5) (17.5) (18.2)		(17.5) (16.7) (17.5)		(16.7) (15.7) (17.2)
Avg		112	(16.3)	127	(18.4)	127	(18.4)	119	(17.2)	114	(16.5)
Avg normalized modulus, 60% F/V	>124 (>18)	120	(17.4)	122	(17.7)	123	(17.9)	112	(16.3)	120	(17.4)
3. Short beam shear strength RT	MN/m^2 (Ksi) >103 (>15)	MN/m^2	(Ksi) (17.6) (16.8) (16.3)	MN/m^2	(Ksi) (18.1) (16.9) (18.0)	MN/m^2	(Ksi) (16.3) (17.4) (17.4)	MN/m^2	(Ksi) (14.2) (12.8) (13.8)	MN/m^2	(Ksi) (7.4) (10.3) (7.7)
Avg		116	(16.9)	122	(17.7)		(17.0)	94	(13.6)	58	(8.5)
316 C (600 F)	>48 (>7)		(5.9) (5.9) (9.3)		(9.1) (9.4) (10.6)		(11.1) (8.6) (8.2)		(7.6) (6.7) (6.5)		(5.1) (4.5) (4.9)
Avg		48	(7.0)	67	(9.7)	64	(9.3)	47	(6.9)	33	(4.8)

(1) The preimidizing 2 stage cure cycle and tooling specified in the 5th Quarterly Report was employed in fabrication of 14 ply unidirectional laminates 17.78 x 13.59 Cm (7.7 x 5.5 inches). Laminates were postcured at 316 C (600 F) for 4 hours, freestanding in an air circulating oven. Prepreg and composite physical properties were calculated per Appendix A of the First Quarterly Report.

(2) Target property values are based on Celion fiber minimum properties of 2618 MN/m^2, (380 Ksi) tensile strength and 234 GN/m^2, (34 Msi) tensile modulus using the rule of mixtures, 60% composite fiber volume. Target 316 C (600 F) strength properties are based on a 60 percent retention of room values.

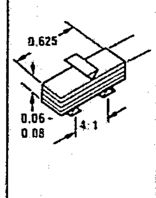
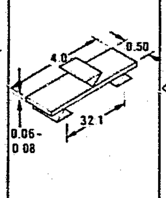
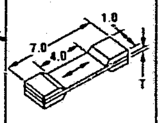
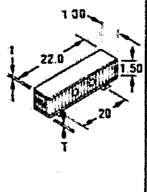
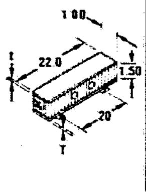
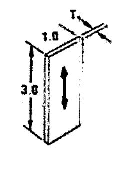
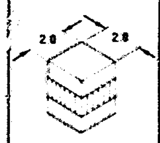
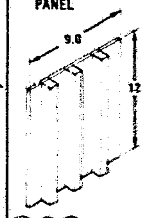
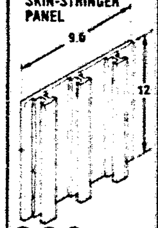
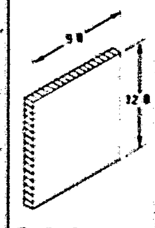
(3) NDE ultrasonic through transmission tests were performed using the NASA-LaRC established "A" sensitivity standards.

(4) Specimens were tested after stabilizing at 316 C (600 F) for 10 minutes.

(5) Volatiles and resin solids content determined on portion of stacked laminate.

(6) T = number of bleeder plies on top surface of laminate; B = number of bleeder plies on bottom surface.

Table 7. Test Matrix Mechanical Properties and Structural Elements

FIBER ORIENTATION	TEST TEMPERATURE °C (F)	INTERLAMINAR SHEAR	FLEXURE	LONGITUDINAL TENSION	BEAM FLEXURE TENSION	BEAM FLEXURE COMPRESSION	COMPRESSION	HONEYCOMB FLATWISE TENSION	HAT STIFFENED SKIN STRINGER PANEL	T-BEAM STIFFENED SKIN-STRINGER PANEL	HONEYCOMB PANEL
		 (1)	 (1)	 FIBERGLASS/Pi TABS (1)	 (1)	 (1)	 (1)	 (1)	 (2)(3)(4)	 (2)(3)(4)	 (2)(3)(4)
		F_{isu}	F_{tu}, E_f	$F_{tu}, E_t\, \epsilon_{tu}\, \nu$	$F_{tu}\, E_t\, \epsilon_{tu}$	$F_{cu}\, E_c\, \epsilon_{cu}$	$F_{cu}\, E_c\, \epsilon_{cu}$	F_{tu}	F_c, ϵ_{cu}	F_c, ϵ_{cu}	F_c, ϵ_{cu}
0°	-132 (-270)	6	6	6	6	6	–	–	2	2	2
	24 (75)	6	6	6	6	6	–	–	2	2	2
	202 (400)	6	6	6	6	6	–	–	–	–	–
	316 (600)	6	6	6	6	6	–	–	2	2	2
90°	-132 (-270)	–	–	6	–	–	6	–			
	24 (75)	–	–	6	–	–	6	–			
	202 (400)	–	–	6	–	–	6	–			
	316 (600)	–	–	6	–	–	6	–			
±45°	-132 (-270)	–	–	6	–	–	6	–			
	24 (75)	–	–	6	–	–	6	–			
	202 (400)	–	–	6	–	–	6	–			
	316 (600)	–	–	6	–	–	6	–			
0, ±45, 90	-132 (-270)	–	–	6	–	6	–	6			
	24 (75)	–	–	6	–	6	–	6			
	202 (400)	–	–	6	–	6	–	6			
	316 (600)	–	–	6	–	6	–	6			

(1) 3 SPECIMENS POST-CURED, 3 SPECIMENS AGED AT 316 C (600F) FOR 125 HOURS
(2) 1 SPECIMEN POST-CURED, 1 SPECIMEN AGED AT 316 C (600F) FOR 125 HOURS
(3) FIBER ORIENTATION IN LAMINATE AS REQUIRED BY SPECIFIC DESIGN (REF 2ND & 3RD QUARTERLY REPORTS)
(4) DESIGN LOAD > 3000 LB/IN. AT ROOM TEMPERATURE

Table 8 . Tensile Properties of LARC-160/Celion Unidirectional (0)5 Oriented Composite, Postcured Condition—Beam Test

Specimen Number (4)	Test (3) Temp. C (F)	F_{tu} Test MN/m^2	(Ksi)	Adjusted (2) MN/m^2	(Ksi)	E_t Test GN/m^2	(Msi)	Adjusted (2) GN/m^2	(Msi)	ϵ ult μ (%)	Failure Mode
EX107T-4	-132		(347)		(321)		(28.28)		(26.50)	1.22 *	Tension, 2 inches both sides of ℄
-5	(-270)		(319)		(296)		(28.00)		(26.24)	1.16 *	Tension on ℄
-6			(304)		(282)		(29.29)		(27.44)	1.04 *	Tension on ℄
	Avg	2228	(323)	2065	(300)	197	(28.52)	184	(26.72)	1.14	
EX107T-1	RT		(300)		(278)		(27.30)		(25.58)	1.12	Tension on ℄
-2			(329)		(304)		(27.80)		(26.04)	1.22	Tension, 1.5 inch off ℄
-3			(284)		(263)		(25.90)		(24.27)	1.11	Tension on ℄
	Avg	2097	(304)	1941	(282)	186	(27.00)	174	(25.30)	1.15	
EX107T-7	204		(296)		(274)		(25.20)		(23.61)	1.15	Tension in center area
-8	(400)		(271)		(251)		(27.70)		(25.95)	1.02	Tension in center area
-9			(262)		(243)		(23.8)		(22.31)	1.07	Tension in center area
	Avg	1076	(276)	1763	(256)	170	(24.7)	160	(23.17)	1.28	
EX107T-10	(316)		>(219)		>(206)		(26.96)		(25.45)	>0.816	Steel face to core failure
-11	(600)		(255)		(239)		(26.95)		(25.44)	0.970	Tension on ℄ and steel face to core
-12			>(174)		>(163)		(22.57)		(21.31)	>0.800	Steel face to core failure
	Avg	1757	(255)	1647	(239)	176	(25.49)	166	(24.07)	0.970	

(1) Tension critical beams per the design described in Second Quarterly Report were employed in test. Aluminum honeycomb 5052 alloy core 1/8 cell, 352 g/m^3 (22 pcf) density was employed in -132 C, RT and 204 C (-220 F, RT and 400 F) tests. CRES core, 301 alloy, 1/8 cell, 0.127 mm (0.005 inch) foil, 40 pcf density was employed in 316 C (600 F) tests.

(2) Adjusted properties were calculated from equations derived by Mr. Mark Shuart, NASA/LaRC using a computer program that considers the effect of bulk core properties on the strength and elastic modulus properties of the laminate. Adjustment factors for -132 C, RT and 204 C(-270 F, RT and 400 F) test temperature: $F_{tu} = \frac{F_{tu}\ \text{test}}{1.0792}$; $E_t = 0.937 \times E_t$ test value. For 316 C (600 F) tests: $F_{tu} = \frac{F_{tu}\ \text{test}}{1.0651}$; $E_t = 0.944 \times E_t$ test value.

(3) Tests were performed at a load rate of 0.127 Cm/minute (0.05 inch/minute) after stabilizing at the test temperature for 10 minutes.

* Projected from point of strain gage failure.

(4) Composite Physical Properties:

Density (grams/cc)	Resin Content (%)	Fiber Vol (%)	Void Vol (%)	Thickness Calculated mm	Thickness Calculated (mils)	Thickness Actual Range mm	Thickness Actual Range (mils)	C-Scan Transmission (%)
1.618	25.6	68.8	-0.65	0.264	(10.4)	0.305-0.330	(12-13)	100

(5) The insitu imidizing-cure cycle specified in the Second Quarterly Report was employed in laminate fabrication, using Hexcel prepreg batch 22796.

Table 9. Tensile Properties of LARC-160/Celion Unidirectional $(0)_5$ Oriented Composite, Aged 125 Hours at 316 C (600 F)—Beam Test

Specimen[4] Number	Test[3] Temp. C (F)	F_{tu} Test MN/m^2	F_{tu} Test (Ksi)	F_{tu} Adjusted[2] MN/m^2	F_{tu} Adjusted[2] (Ksi)	E_t Test GN/m^2	E_t Test (Msi)	E_t Adjusted[2] GN/m^2	E_t Adjusted[2] (Msi)	ε ult μ (%)	Failure Mode
EX199T-1	-132		(281)		(260)		(26.3)		(24.6)	12.5	Tensile failure on ℄
-2	(-270)		(245		(227)		(28.9		(27.0)	9.6	Tensile failure on C
-3			(286)		(265)		(24.7)		(23.1)	12.3	Tensile failure on ℄
	Avg	1867	(271)	1727	(251)	184	(26.6)	172	(24.4)	11.5	
EX199T-4	RT		(317)		(294)		(25.5)		(23.9)	13.3	Tensile failure 1.0 inch off ℄
-5			(340)		(315)		(25.3)		(23.7)	13.3	Tensile failure on ℄
-6			(331)		(307)		(24.0)		(22.5)	14.1	Tensile failure on ℄
	Avg	2269	(329)	2104	(305)	172	(24.9)	161	(23.4)	13.6	
EX199T-10	204		(159)		(243)	—*	—	—	—	—	Tensile failure on ℄
-11	(400)		(249)		(231)		(27.6)		(25.8)	9.4	Tensile failure on ℄
-12			(>257)		(>238)		(29.7)		(27.8)	>8.8	Bond failure specimen to core
	Avg	1750	(254)	1633	(237)	197	(28.7)	185	(26.8)	9.4	
EX199T-7	(316)		(>128)		(>120)		(26.7)		(25.2)	>4.5	Bond failure steel face/core
-8	(600)		(>144)		(>135)		(26.3)		(24.8	>5.5	Bond failure steel face/core
-9			(>166)		(>156)		(25.9)		(24.5)	>6.4	Bond failure steel face/core
	Avg		—	—	—	181	(26.3)	171	(24.8)	—	

(1) Tension critical beams per the design described in Second Quarterly Report were employed in test. Aluminum honeycomb 5052 alloy core, 1/8 cell, 352 g/m^3 (22 pcf) density was employed in -132 C, RT and 204 C (-220 F, RT and 400 F) tests. CRES core, 301 alloy, 1/8 cell, 0.127 mm (0.005 inch) foil, 40 pcf density was employed in 316 C (600 F) tests.

(2) Adjusted properties were calculated from equations derived by Mr. Mark Shuart, NASA /LaRC using a computer program that considers the effect of bulk core properties on the strength and elastic modulus properties of the laminate. Adjustment factors for -132 C, RT and 204 C (-270 F, RT and 400 F) test temperature:

$$F_{tu} = \frac{F_{tu\ test}}{1.0792};\ E_t = 0.937 \times E_t \text{ test value. For 316 C (600 F) tests:}$$

$$F_{tu} = \frac{F_{tu\ test}}{1.0651};\ E_t = 0.944 \times E_t \text{ test value.}$$

(3) Tests were performed at a load rate of 0.127 Cm/minute (0.05 inch/minute) after stabilizing at the test temperature for 10 minutes.

(4) Composite Physical Properties:

Density (grams/cc)	Resin Content (%)	Fiber Vol (%)	Void Vol (%)	Thickness Calculated mm	Thickness Calculated (mils)	Thickness Actual Range mm	Thickness Actual Range (mils)	C-Scan Transmission (%)	Wt Loss After 125 Hours at 316 C (600 F) (%)
1.601	29.9	63.4	-0.22	0.284	(11.2)	0.279-0.318	(11-12.5)	99	3.4

(5) The preimidizing 2 stage cure cycle specified in the Fourth Quarterly Report was employed in laminate fabrication, using Hexcel prepreg batch 22796.

*Strain gage failure.

Table 10. Compressive Properties of LARC-160/Celion Unidirectional $(0)_5$ Oriented Composite Postcured Condition—Beam Test

Specimen[4] Number	Test[3] Temp C (F)	F_{cu} Test MN/m^2	F_{cu} Test (Ksi)	F_{cu} Adjusted[2] MN/m^2	F_{cu} Adjusted[2] (Ksi)	E_c Test GN/m^2	E_c Test (Msi)	E_c Adjusted[2] GN/m^2	E_c Adjusted[2] (Msi)	ε ult μ (%)	Failure Mode
EX107C-4	-132 (-270)		(295)		(273)		(24.76)		(23.20)	1.42	Compression on ℄
-5			(274)		(254)		(24.67)		(23.12)	1.34	Compression 1.0 inch off ℄
-6			(283)		(262)		(24.31)		(22.78)	1.51	Compression 2.0 inch both sides ℄
Avg		1957	(284)	1812	(263)	164	(24.58	159	(23.03)	1.42	
EX107C-1	RT		(223)		(207)		(22.34)		(20.93)	1.11	Compression overloading hole
-2			(208)		(193)		(22.97)		(21.52)	0.976	Compression on ℄
-3			(214)		(198)		(22.20)		(20.80)	1.05	Compression on ℄
Avg		1481	(215)	1373	(199)	155	(22.50)	145	(20.98)	1.05	
EX10C-7	204 (400)		>(102)		>(95.7)		(22.6)		(21.18)	>0.472	Composite to core bond failure
-8			(183)		(170)		(21.8)		(20.42)	0.960	Compression on ℄
-9		—	—	—	—	—	—	—	—	—	No test damaged specimen
Avg		1261	(183)	1171	(170)	150	(21.8)	141	(20.4)	0.960	
EX107C-10	316 (600)		(121)		(114)		(20.88)		(19.71)	0.610	Compression on ℄
-11			(142)		(133)		(22.24)		(21.00)	0.660	Compression 1.5 inch off ℄
-12			(145)		(136)		(22.20)		(20.95)	0.660	Compression 1.75 inch off ℄
Avg		937	(136)	(880)	(128)	150	(21.77)	141	20.55	0.643	

(1) Compression critical beams per the design described in Second Quarterly Report were employed in test. Aluminum honeycomb 5052 alloy core 1/8 cell, 352 g/m^3 (22 psf) density was employed in -132 C, RT & 204 C (-270 F, RT & 400 F) tests, CRES Core, 301 Alloy, 1/8 cell, 0.127 mm (0.005 inch) foil 40 pcf was employed in 316 C (600 F) tests.

(2) Adjusted properties were calculated from equations derived by Mr. Mark Shuart, NASA/LaRC using a computer program that considers the effect of bulk core properties on the strength & elastic modulus properties of the laminate. Adjustment factors for -132 C, RT & 204 C (-270 F, RT & 400 F) test temperature: $F_{cu} = \frac{F_{cu}\ \text{test}}{1.0792}$; $E_c = 0.937 \times E_c$ test value. For 316 C (600 F) tests: $F_{cu} = \frac{F_{cu}\ \text{test}}{1.0651}$; $E_c = 0.944 \times E_c$ test value.

(3) Tests were performed at a load rate of 0.127 cm/minutes (0.05 inch/minute) after stabilizing at the test temperature for 10 minutes.

(4) Composite Physical Properties:

Density (grams/cc)	Resin Content (%)	Fiber Vol (%)	Void Vol (%)	Thickness Calculated mm	Thickness Calculated (mils)	Thickness Actual Range mm	Thickness Actual Range (mils)	C-Scan Transmission (%)
1.618	25.6	68.8	-0.65	0.264	(10.4)	0.305-0.330	(12-23)	100

(5) The insitu imidizing-cure cycle specified in the Second Quarterly Report was employed in laminate fabrication, using Hexcel prepreg batch 22796.

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Space Transportation System
Development & Production Division
Space Systems Group
Rockwell International

Table 11. Compressive Properties of LARC-160/Celion Unidirectional $(0)_5$ Oriented Composite, Aged 125 Hours at 316 C (600 F)—Beam Test

Specimen(4) Number	Test(3) Temp C (F)	F_{cu} Test MN/m²	F_{cu} Test (Ksi)	F_{cu} Adjusted(2) MN/m²	F_{cu} Adjusted(2) (Ksi)	E_c Test GN/m²	E_c Test (Msi)	E_c Adjusted(2) GN/m²	E_c Adjusted(2) (Msi)	ε ult μ (%)	Failure Mode
EX199C-1	-132		(257)		(221)	—*	—	—	—	—	Compression 1.5 inch off ℄
-2	(-270)		(284)		(263)		(23.3)		(21.8)	11.7	Compression on ℄
-3			(261)		(242)		(23.6)		(22.1)	13.9	Compression on ℄
Avg		1842	(267)	1667	(242)	162	(23.5)	151	(22.0	12.8	
EX199C-4			(198)		(184)		(21.1)		(19.8)	10.5	Compression on ℄
-5	RT		(264)		(245)		(20.7)		(19.4)	14.4	Compression 1.25 inch off ℄
-6			(257)		(238)		(21.6)		(20.2)	13.7	Compression over loading hole
Avg		1653	(240)	1529	(222)	145	(21.1)	136	(19.8)	12.9	
EX199C-10	204		(128)		(119)	—*	—	—	—	—	Compression 1.5 inch off ℄
-11	(400)		(123)		(114)		(28.1)		(26.3)	4.60	Compression 1.0 inch off ℄
-12			(112)		(104)		(23.4)		(21.9	4.80	Compression 0.5 inch off ℄
Avg		834	(121)	774	(112)	177	(25.8)	166	(24.1)	4.7	
EX199C-7	316		(127)		(119)	—*	—	—	—	—	Compression 1.0 inch off ℄
-8	(600)		(122)		(114)		(24.2)		(22.8)	5.40	Compression on ℄
-9			(89.1)		(83.7)		(24.3)		(22.9)	3.94	Compression 1.0 inch off ℄
Avg		777	(113)	727	(106)	167	(24.3)	157	(22.9	4.67	

(1) Compression critical beams per the design described in Second Quarterly Report were employed in test. Aluminum honeycomb 5052 alloy core, 1/8 cell, 352 g/m³ (22 psf) density was employed in -132 C, RT and 204 C (-270 F, RT and 400 F) tests, CRES core, 301 alloy, 1/8 cell, 0.127 mm (0.005 inch) foil 40 pcf was employed in 316 C (600 F) tests.

(2) Adjusted properties were calculated from equations derived by Mr. Mark Shuart, NASA/LaRC using a computer program that considers the effect of bulk core properties on the strength and elastic modulus properties of the laminate. Adjustment factors for -132 C, RT and 204 C (-270 F, RT and 400 F) test temperature:

$$F_{cu} = \frac{F_{cu\ test}}{1.0792};\ E_c = 0.937 \times E_c \text{ test value. For 316 C (600 F) tests:}$$

$$F_{cu} = \frac{F_{cu\ test}}{1.0651};\ E_c = 0.944 \times E_c \text{ test value.}$$

(3) Tests were performed at a load rate of 0.127 cm/minutes (0.05 inch/minute) after stabilizing at the test temperature for 10 minutes.

(4) Composite Physical Properties:

Density (grams/cc)	Resin Content (%)	Fiber Vol (%)	Void Vol (%)	Thickness Calculated mm	Thickness Calculated (mils)	Thickness Actual Range mm	Thickness Actual Range (mils)	C-Scan Transmission (%)	Wt Loss After 125 Hours at 316 C (600 F) (%)
1.601	29.9	63.4	-0.22	0.284	(11.2)	0.279-0.318	(11-12.5)	99	3.4

(5) The preimidizing 2 stage cure cycle specified in the Fourth Quarterly Report was employed in laminate fabrication, using Hexcel prepreg batch 22796.

*Strain gage failure

Table 12. Compressive Properties of LARC-160/Celion (0, ±45, 90)$_S$ Oriented Composite, Postcured Condition—Beam Test

(4)(5) Specimen Number	Test(3) Temp C (F)	F_{cu} Test MN/m^2	F_{cu} Test (ksi)	F_{cu} Adjusted(2) MN/m^2	F_{cu} Adjusted(2) (ksi)	E_c Test GN/m^2	E_c Test (msi)	E_c Adjusted(2) GN/m^2	E_c Adjusted(2) (msi)	ε ult μ (%)	Failure Mode
EX106C-4	-132		(117)		(98.4)		–		–	–	Compression on ℄
-5	(-270)		(138)		(116)		(10.43)		(9.13)	1.73	Compression overloading hole
-6			(118)		(99.2)		(10.10)		(8.83	1.14	Compression in center
	Avg	857	(124)	720	(105)	70.73	(10.27)	61.87	(8.98)	1.44	
EX106C-1			(116)		(97.5)		(10.15)		(8.88)	1.33	Compression overloading hole
-2	RT		(113)		(95.0)		(10.90)		(9.54)	1.16	Compression on ℄
-3			(95)		(79.9)		(9.50)		(8.31)	1.11	Compression on ℄
	Avg	744	(108)	626	(90.8)	70.16	(10.18)	61.39	(8.91)	1.21	
EX106C-7	204		>(68.1)		>(57.20)		(7.83)		(6.85)	>0.950	Composite-to-core bond failure
-8	(400)		>(81.8)		>(68.75)		(8.70)		(7.61)	>1.10	Composite-to-core bond failure
-9			>(85.73)		>(72.08)		(8.04)		(7.04)	>1.16	Composite-to-core bond failure
	Avg	541	(78.5)	455	>(66.01)	56.43	(8.19)	49.38	(7.17)		
EX106C-10	316		(66.1)		(59.1)		(7.99)		(7.22)	0.984	Compression on ℄
-11	(600)		>(69.4)		>(62.0)		(8.50)		(7.68)	>0.906	Composite-to-core bond failure
-12		[657]	[95.3]	[587]	[85.2]	[68.9]	[10.00]	[62.3]	[9.04]	[0.890]	[Tested in tension—tensile failure]
-13			>(80.1)		>(71.6)		(9.8)		(8.86)	>1.00	Composite-to-core bond failure
-14			(91.8)		(82.0)		10.02		9.06	1.16	Compression on ℄
	Avg	544	79.0	486	70.6	62.0	(9.05)	56.0	(8.14)	1.07	

(1) Compression critical beams per the design described in Second Quarterly Report were employed in test. Aluminum honeycomb 5052 alloy core, 1/8 cell, 352 g/m^3 (22 pcf) density was employed in -132 C, RT and 204 C (-220 F, RT and 400 F) tests. CRES core, 301 alloy, 1/8 cell, 0.127 mm (0.005 inch) foil, 40 pcf employed in 316 C (600 F) tests.

(2) Adjusted properties were calculated from equations derived by Mr. Mark Shuart, NASA/LaRC using a computer program that considers the effect of bulk core properties on the strength and elastic modulus properties of the laminate. Adjustment factors for -132 C, RT and 204 C (-220 F, RT, and 400 F) test temperatures: $F_{cu} = \frac{F_{cu} \text{ test}}{1.1893}$, $E_c = 0.875 \times E_c$ test value. For 316 C (600 F) tests: $F_{cu} = \frac{F_{cu} \text{ test}}{1.1192}$; $E_c = 0.904X\ E_c$ test value.

(3) Tests were performed at a load rate of 0.127 cm/minute (0.05 inch/minute) after stabilizing at the test temperature for 10 minutes.

(4) Composite Physical Properties:

Density (grams/cc)	Resin Content (%)	Fiber Vol (%)	Void Vol (%)	Thickness Calculated mm	Thickness Calculated (mils)	Thickness Actual Range mm	Thickness Actual Range (mils)	C-Scan Transmission (%)	TMA-Tg (C)
1.588	30.2	62.9	0.47	0.461	(18.1)	0.457-0.503	(18-20)	100	362

(5) The insitu imidizing-cure cycle specified in the Second Quarterly Report was employed in laminate fabrication, using Hexcel prepreg batch 22796.

Table 13. Compressive Properties of LARC-160/Celion (0, ±45, 90)s Oriented Composite, Aged 125 Hours at 316 C (600 F)—Beam Test

Specimen(4)(5) Number	Test(3) Temp C (F)	F_{cu} Test MN/m^2	F_{cu} Test (Ksi)	F_{cu} Adjusted(2) MN/m^2	F_{cu} Adjusted(2) (Ksi)	E_c Test GN/m^2	E_c Test (Msi)	E_c Adjusted(2) GN/m^2	E_c Adjusted(2) (Msi)	ε ult μ (%)	Failure Mode
EX200C-1	132		(122)		(103)	—*		—	—	—	Compression over loading hole
-2	(-270)		(79.1)		(66.5)		(9.60)		(8.40)	9.44	Compression over loading hole
-3			(82.5)		(69.4)		(9.10)		(7.96)	9.80	Compression 1.5 inch off ℄
Avg		651	(94.5)	548	(79.6)	64.4	(9.35)	56.4	(8.18)	9.62	
EX200C-4			(90.1)		(75.7)		(10.50)		(9.19)	10.00	Compression on ℄
-5	RT		(102)		(85.9)		(8.50)		(7.44)	14.00	Compression outside loading hole
-6			(102)		(85.7)		(8.48)		(7.13)	13.90	Compression on ℄
Avg		675	(98.0)	568	(82.4)	63.1	(9.16)	54.6	(7.92)	12.63	
EX200C-10	204		(77.8)		(65.4)	—*	—	—	—	—	Compression over loading hole
-11	(400)		(66.4)		(55.8)		(8.08)		(7.07)	9.80	Compression on ℄
-12			(87.5)		(73.6)		(8.13)		(7.11)	13.10	Compression over loading hole
Avg		532	(77.2)	447	(64.9)	55.9	(8.11)	48.9	(7.09)	11.45	
EX200C-7	316		(65.7)		(58.7)	—*	—	—	—	—	Compression 1.25 inch off ℄
-8	(600)		(80.8)		(72.2)		(8.88)		(8.02)	11.40	Compression over loading hole
-9			(69.1)		(61.8)		(8.48)		(7.66)	9.80	Compression on ℄
Avg		495	(71.8)	442	(64.2)	59.8	(8.68)	54.0	(7.84)	10.6	

(1) Compression critical beams per the design described in Second Quarterly Report were employed in test. Aluminum honeycomb 5052 alloy core, 1/8 cell, 352 g/m3 (22 pcf) density was employed in -132 C, RT and 204 C (-220 F, RT and 400 F) tests. CRES core, 301 alloy, 1/8 cell, 0.127 mm (0.005 inch) foil, 40 pcf employed in 316 C (600 F) tests.

(2) Adjusted properties were calculated from equations derived by Mr. Mark Shuart, NASA/LaRC using a computer program that considers the effect of bulk core properties on the strength and elastic modulus properties of the laminate. Adjustment factors for-132 C, RT and 204 C (-220 F, RT, and 400 F) test temperatures:

$$F_{cu} = \frac{F_{cu\ test}}{1.1893}, \; E_c = 0.875 \times E_c \text{ test value. For 316 C (600 F) tests:}$$

$$F_{cu} = \frac{F_{cu\ test}}{1.1192}; \; E_c = 0.904 \times E_c \text{ test value.}$$

(3) Tests were performed at a load rate of 0.127 cm/minute (0.05 inch/minute) after stabilizing at the test temperature for 10 minutes.

(4) Composite Physical Properties:

Density (grams/cc)	Resin Content (%)	Fiber Vol (%)	Void Vol (%)	Thickness Calculated mm	Thickness Calculated (mils)	Thickness Actual Range mm	Thickness Actual Range (mils)	C-Scan Transmission (%)	TMA-Tg (C)	Wt Loss After 125 Hrs at 316 C (600 F) (%)
1.594	31.2	62.0	-0.21	0.465	(18.32)	0.48-0.54	(19-21.5)	100	365	3.2

(5) The preimidizing 2 stag_ cure cycle specified in the Fourth Quarterly Report was employed in laminate fabrication, using Hexcel prepreg batch 22796.

*Strain gage failure.

Table 14. Summary of LARC-160/Celion Tensile Properties

Panel No. & Spec.	Fiber Orientation/ Specimen	Tensile Property(1)	Test Temperature: Postcured -132 C (-270 F)	Postcured RT	Postcured 204 C (400 F)	Postcured 316 C (600 F)	Aged 125 Hours at 316 C (600 F): -132 C (-270 F)	Aged RT	Aged 204 C (400 F)	Aged 316 C (600 F)
EX107 (P.C.)	$(0)_t$/ Beam	F_{tu} MN/m^2	2065	1941	1076	1647	1727	2104	1633	--
		(Ksi)	(300)	(282)	(276)	(239)	(251)	(305)	(237)	--
EX199 (Aged)		E_t GN/m^2	184	174	160	166	172	161	185	171
		(Msi)	(26.72)	(25.30)	(23.7)	(24.07)	(24.4)	(23.4)	(26.8)	24.8
		ϵ ULT μ (%)	1.14	1.15	1.28	0.970	1.51	1.36	0.94	--
		ν	0.370	0.275	0.310	0.310	--	--	--	--
EX98 (P.C.)	$(90)_t$/ Coupon	F_{tu} MN/m^2	35.6	23.0	15.8	18.1	47.3	35.1	12.1	14.0
		(Ksi)	(5.17)	(3.34)	(2.30)	(2.63)	(6.87)	(5.10)	(1.75)	(2.03)
EX201 (Aged)		E_t GN/m^2	11.02	9.20	8.20	5.23	TBD	TBD	TBD	TBD
		(Msi)	1.60	1.60	(1.19)	0.759	TBD	TBD	TBD	TBD
		ϵ ULT μ (%)	0.33	0.33	0.20	0.37	TBD	TBD	TBD	TBD
		ν	0.068	0.068	0.041	0.031	TBD	TBD	TBD	TBD
EX105 (P.C.)	$(\pm 45)_S$/ Coupon	F_{tu} MN/m^2	201	201	149	141	15.7	134	132	103
		(Ksi)	29.1	29.1	(21.6)	(20.5)	(22.8)	(19.4)	(19.1)	(14.9)
EX202 (Aged)		E_t GN/m^2	27.69	27.69	20.26	17.71	TBD	TBD	TBD	TBD
		(Msi)	(4.02)	(4.02)	(2.94)	(2.57)	TBD	TBD	TBD	TBD
		ϵ ULT μ (%)	0.74	0.74	--	--	TBD	TBD	TBD	TBD
		ν	0.75	0.75	0.84	0.92	TBD	TBD	TBD	TBD
EX106 (P.C.)	$(0,\pm 45,90)_S$ Coupon	F_{tu} MN/m^2	517	569	556	560	480	446	434	491
		(Ksi)	(74.9)	(82.5)	(80.7)	(81.3)	(69.6)	(64.7)	(63.3)	(71.3)
EX200 (Aged)		E_t GN/m^2	56.03	53.28	55.14	41.96	TBD	TBD	49.61	TBD
		(Msi)	(8.13)	(7.73)	(8.00)	(6.09)	TBD	TBD	(7.2)	TBD
		ϵ ULT μ (%)	0.96	1.10	1.02	0.89	TBD	TBD	TBD	TBD
		ν	0.320	0.295	0.325	0.300	TBD	TBD	TBD	TBD

(1) ν Poissons ratio values reported for tension beam specimens were calculated from coupon specimen data.

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Table 15. Tensile Properties of LARC-160/Celion $(0)_5$ Oriented Postcured Composites(1)(2)

Specimen (4) Number	Test (3) Temperature C (F)	F_{tu} (5) MN/m²	(Ksi)	E_t GN/m²	(MSI)	ν_t	ε Ult μ (%)
EX107-2-1	-132	1626	(236)		(24.5)	—	0.96A
-2-2	(-270)	1605	(233)		(22.5)	0.390	1.08 *
-2-3		1743	(253)	—	(21.6)	0.350	1.16 *
				Avg 158	(22.2)	0.370	
EX107-1-1		1709	(248)		(23.0)	—	1.05A
-1-2	RT	950	(137)		(18.4)	0.260	0.75 *
-1-3		1337	(194)	—	(21.4)	0.290	0.89 *
				Avg 145	(21.1)	0.275	
EX107-3-1	204	1633	(232)		(21.7)	—	1.17A
-3-2	(400)	1578	(229)		(21.6)	0.330	0.98*
-3-3		1357	(197)	—	(24.4)	0.290	0.81*
				Avg 156	(22.6)	0.310	
EX107-4-1	316	1357	(197)		(21.3)	—	0.90A
-4-2	(600)	1240	(180)		—	—	—
-4-3		1433	(208)	—	(24.0)	0.310	0.87*
				Avg 156	(22.7)	0.310	

(1) Coupon tensile specimen design, straight sides, 2.54 cm (1.00 inch) wide per Third Quarterly Report. Laminate consisted of 5 ply 0° oriented, nominal 0.064 cm (2.5 mils) per ply, Hexcel batch 22796.

(2) Composite Physical Properties:

Density (grams/cc)	Resin Content (%)	Fiber Vol (%)	Void Vol (%)	Thickness Calculated mm	Thickness Calculated (mils)	Thickness Actual Range mm	Thickness Actual Range (mils)	C-Scan Transmission (%)
1.618	25.6	68.8	-0.65	0.264	(10.4)	0.305-0.330	(12-13)	100

(3) Load was applied at 1.27 mm/minute (0.05 inch) after specimens had stabilized at test temperature for 10 minutes. Strain gaged specimens were loaded incrementally to allow for data aquisition.

(4) -1 specimens were tested with a 5.08 cm (2.0 inch) gage length extensometer. Specimens -2 and 3 tested at -132 C and 316 C (-270 F and 600 F) employed type WK-00-125AD-350 gages; -2 and 3 specimens tested at 204 C (400 F), type OK-00-125A-A-350 (LEN) gages; -2 and 3 specimens tested at RT, type CEA-00-125UT-350 gages.

(5) Ftu data points were not averaged since strain gaged specimens were not tested under a constant loading condition.

*** Projected from last strain gage reading**

A Actual

Table 16. Tensile Properties of LARC-160/Celion $(0)_5$ Oriented Composite, Aged 125 Hours at 316 C (600 F) (1) (2)

Specimen Number (4)	Test Temperature (3) C (F)	F_{tu}		E_t		νt	ϵ Ult μ (%)
		MN/m²	(Ksi)	GN/m²	(MSI)		
EX199TC-1	-132		207		22.1		
-2	(-270)		182			TBD	TBD
-3			-*				
	AVG	1340	195				
EX199TC-4			192		22.8		
-5	RT		-**			TBD	TBD
-6			199				
	AVG	1347	196				
EX199TC-7	204		211		24.1		
-11	(400)		-**			TBD	TBD
-12			201				
	AVG	1419	206				
EX199TC-8	316		-**				
-9	(600)		-**			TBD	TBD
-10			-**		20.8		
	AVG						

(1) Coupon tensile specimen design, straight sides, 2.54 cm (1.00 inch) wide per Third Quarterly Report. Laminate consisted of 5 ply 0° oriented, nominal 0.064 cm (2.5 mils) per ply, Hexcel batch 22796.

(2) Composite Physical Properties:

Density (grams/cc)	Resin Content (%)	Fiber Vol (%)	Void Vol (%)	Thickness: Calculated mm	Thickness: Calculated (mils)	Thickness: Actual Range mm	Thickness: Actual Range (mils)	C-Scan Transmission (%)	Wt Loss After 125 Hours at 316 C (600 F) %
1.601	29.9	63.4	-0.22	0.284	(11.2)	0.279-0.318	(11-12.5)	100	3.4

(3) Load was applied at 1.27 mm/minute (0.05 inch) after specimens had stabilized at test temperature for 10 minutes. Strain gaged specimen data aquisition was obtained autographically on two X, Y, Y recorders.

(4) -1 specimens were tested with a 5.08 cm (2.0 inch) gage length extensometer. Specimens -2 and 3 tested at -132 C and 316 C (-270 F and 600 F) employed type WK-00-125AD-350 gages; -2 and 3 specimens tested at 204 C (400 F), type OK-00-125A-A-350 (LEN) gages; -2 and 3 specimens tested at RT, type CEA-00-125UT-350 gages.

* Damaged specimen

**Graphite/polyimide tab caused slipping in grips, damaged specimen.

Table 17. Tensile Properties of LARC-160/Celion (90)40 Oriented Postcured Composites(1) (2)

Specimen (4) Number	Test (3) Temperature C (F)	F_{tu} (5) MN/m^2	F_{tu} (5) (Ksi)	E_t GN/m^2	E_t (MSI)	ν_t	ε Ult μ (%)
EX98-2-1	-132	24.05	(3.49)	—	(1.63)	—	0.21 A
-2-2	(-270)	47.20	(6.85)		(1.57)	0.068	0.45*
-2-3		—	—	—	—	—	—
				Avg 11.02	(1.60)	0.068	
EX98-1-1		24.87	(3.61)		(1.26)	—	0.28 A
-1-2	RT	—	—	—	—	—	—
-1-3		21.15	(3.07)		(1.41)	0.051	0.22*
				Avg 9.20	(1.34)	0.051	
EX98-3-1	204	15.16	(2.20)		(1.11)	—	0.20 A
-3-2	(400)	15.23	(2.21)		(1.28)	0.032	0.17*
-3-3		17.16	(2.49)		(1.18)	0.049	0.22*
				Avg 8.20	(1.19)	0.041	
EX98-4-1	316	24.87	(3.61)		(0.883)	—	0.43A
-4-2	(600)	14.74	(2.14)		(0.740)	0.021	0.33*
-4-3		14.81	(2.15)		(0.653)	0.041	0.35*
				Avg 5.23	(0.759)	0.031	

(1) Coupon tensile specimen design straight sides, 2.54 cm (1.0 inch) wide per Third Quarterly Report. Laminate consisted of 40 ply 90° oriented, nominal 0.064 cm (2.5 mils) per ply, Hexcel batch 22796.

(2) Composite Physical Properties:

Density (grams/cc)	Resin Content (%)	Fiber Vol (%)	Void Vol (%)	Thickness Calculated mm	Thickness Calculated (mils)	Thickness Actual Range mm	Thickness Actual Range (mils)	C-Scan Transmission (%)	TMA-Tg (C)
1.598	28.4	65.4	-0.29	2.21	86.7	1.80-2.05	75-81	100	340

(3) Load was applied at 1.27 mm/minute (0.05 inch) after specimens had stabilized at test temperature for 10 minutes. Strain gaged specimens were loaded incrementally to allow for data aquisition.

(4) -1 specimens were tested with a 5.08 cm (2.0 inch) gage length extensometer. Specimens -2 and 3 tested at -132 C and 316 C (-270 F and 600 F) employed type WK-00-125AD-350 gages; -2 and 3 specimens tested at 204 C (400 F), type OK-00-125a-a-350 (LEN) gages; -2 and 3 specimens tested at RT, type CEA-00-125UT-350 gages.

(5) Ftu data points were not averaged since strain gaged specimens were not tested under a constant loading condition.

*** Projected from last strain gage reading**

A Actual

Table 18. Tensile Properties of LARC-160/Celion $(90)_{40}$ Oriented Composite Aged 125 Hours at 316 C (600 F) (1) (2)

Specimen (4) Number	Test (3) Temperature C (F)	F_{tu} MN/m^2	F_{tu} (Ksi)	E_t GN/m^2	E_t (MSI)	νt	ϵ Ult μ (%)
EX201TC-1	-132		6.90			-	
-2	(-270)		6.85	TBD	TBD	TBD	TBD
-3			-*				
Avg		47.3	6.87				
EX201TC-4			4.80	9.64	1.4		
-5	RT		5.40	TBD	TBD	TBD	TBD
-6			5.10				
Avg		35.1	5.10				
EX201TC-7	204		1.90	7.57	1.1		
-10	(400)		1.60	TBD	TBD	TBD	TBD
Avg		12.1	1.75				
EX201-8	316		1.80				
-9	(600)		2.30	TBD	TBD	TBD	TBD
-11			2.00				
Avg		14.0	2.03				

(1) Coupon tensile specimen design straight sides, 2.54 cm (1.0 inch) wide per Third Quarterly Report. Laminate consisted or 40 ply 90° oriented, nominal 0.064 cm (2.5 mils) per ply, Hexcel batch 22796.

(2) Composite Physical Properties:

Density (grams/cc)	Resin Content (%)	Fiber Vol (%)	Void Vol (%)	Thickness Calculated mm	Thickness Calculated (mils)	Thickness Actual Range mm	Thickness Actual Range (mils)	C-Scan Transmission (%)	TMA-Tg (C)	Wt/ Loss After 125 Hours at 316C (600F) %
1.604	30.0	63.4	-0.45	2.27	(89.2)	2.48-2.57	(98-101)	100	359	0.86

(3) Load was applied at 1.27 mm/minute (0.05 inch) after specimens had stabilized at test temperature for 10 minutes. Strain gaged specimen data aquisition was obtained autographically using X, Y, Y recorders.

(4) -1 specimens were tested with a 5.08 cm (2.0 inch) gage length extensometer. Specimens -2 and 3 tested at -132 C and 316 C (-270 F and 600 F) employed type WK-00-125AD-350 gages; -2 and 3 specimens tested at 204 C (400 F), type OK-00-125a-a-350 (LEN) gages; -2 and 3 specimens tested at RT, type CEA-00-125UT-350 gages.

* Damaged specimen.

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Table 19. Tensile Properties of LARC-160/Celion $(\pm 45)_S$ Oriented Postcured Composites[1] [2]

Specimen Number (4)	Test (3) Temperature C (F)	F_{tu} (5)		E_t		ν_t	ε Ult μ (%)
		MN/m²	(Ksi)	GN/m²	(MSI)		
EX105-2-1	-132	200	(29.1)		(3.58)	—	—
-2-2	(-270)	209	(30.4)		(4.30)	0.72	0.74*
-2-3		192	(27.9)		(4.17)	0.77	0.70*
			Avg	27.69	(4.02)	0.75	
EX105-1-1		176	(25.5)		(3.10)		—
-1-2	RT	163	(23.7)		(3.48)	0.77	—
-1-3		168	(24.7)		(3.22)	0.74	—
			Avg	22.25	(3.23)	0.76	
EX105-3-1	204	164	(23.8)		(2.53)	—	—
-3-2	(400)	149	(21.6)		(3.15)	0.75	—
-3-3		135	(19.6)		(3.15)	0.93	—
			Avg	20.26	(2.94)	0.84	
EX105-4-1	316	150	(21.8)		(2.15)	—	—
-4-2	(600)	130	(18.9)		(2.22)	0.93	—
-4-3		143	(20.7)		(3.33)	0.91	—
			Avg	17.71	(2.57)	0.92	

(1) Coupon tensile specimen design, straight sides, 2.54 cm (1.0 inch) wide per Third Quarterly Report. Laminate consisted of 4 ply $(\pm 45)_S$ oriented, nominal 0.064 cm (2.5 mils) per ply, Hexcel batch 22796.

(2) Composite Physical Properties:

Density (grams/cc)	Resin Content (%)	Fiber Vol (%)	Void Vol (%)	Thickness Calculated		Thickness Actual Range		C-Scan Transmission (%)
				mm	(mils)	mm	(mils)	
1.592	29.0	64.6	-0.10	0.223	8.88	0.229-0.254	9-10	100

(3) Load was applied at 1.27 mm/minute (0.05 inches) after specimens had stabilized at test temperature for 10 minutes. Strain gaged specimens were loaded incrementally to allow for data aquisition.

(4) -1 specimens were tested with a 5.08 cm (2.0 inch) gage length extensometer. Specimens -2 and 3 tested at -132 C and 316 C (-270 F and 600 F) employed type WK-00-125AD-350 gages; -2 and 3 specimens tested at 204 C (400 F), type OK-00-125A-A-350 (LEN) gages; -2 and 3 specimens tested at RT, type CEA-00-125UT-350 gages.

(5) Ftu data points were not averaged since strain gaged specimens were not tested under a constant loading condition.

*Projected from last strain gage reading.

Table 20. Tensile Properties of LARC-160/Celion ($\pm$ 45)$_S$ Oriented Composite, Aged 125 Hours at 316 C (600 F) (1) (2)

Specimen[4] Number	Test[3] Temperature C (F)	F_{tu}		E_t		νt	ϵ Ult μ (%)
		MN/m^2	(Ksi)	GN/m^2	(MSI)		
EX202TC-1	-132		(23.1)	8.27	1.2		
-2	(-270)		(21.3)	TBD	TBD	TBD	TBD
-3			(24.0)				
	Avg	157	(22.8)				
EX202TC-4			(17.6)	14.5	2.1		
-5	RT		(18.7)	TBD	TBD	TBD	TBD
-6			(21.9)				
	Avg	134	(19.4)				
EX202TC-7	204		(19.2)	16.5	2.4		
-11	(400)		-*	TBD	TBD	TBD	TBD
-12			(19.0)				
	Avg	132	(19.1)				
EX202-8	316		(14.0)				
-9	(600)		(15.0)	TBD	TBD	TBD	TBD
-10			(15.7)	12.4	1.8		
	Avg	103	(14.9)				

(1) Coupon tensile specimen design, straight sides, 2.54 cm (1.0 inch) wide per Third Quarterly Report. Laminate consisted of 4 ply ($\pm$ 45)$_S$ oriented, nominal 0.064 cm (2.5 mils) per ply, Hexcel batch 22796.

(2) Composite Physical Properties:

Density (grams/cc)	Resin Content (%)	Fiber Vol (%)	Void Vol (%)	Thickness				C-Scan Transmission (%)	Wt. Loss After 125 Hours at 316 C (600 F) %
				Calculated		Actual Range			
				mm	(mils)	mm	(mils)		
1.580	33.6	59.26	-0.10	0.238	(9.36)	0.203-0.254	(8-10)	100	5.2

(3) Load was applied at 1.27 mm/minute (0.05 inches) after specimens had stabilized at test temperature for 10 minutes. Strain gaged specimen data acquisition was obtained autographically using two X, Y, Y recorders

(4) -1 specimens were tested with a 5.08 cm (2.0 inch) gage length extensometer. Specimens -2 and 3 tested at -132 C and 316 C (-270 F and 600 F) employed type WK-00-125AD-350 gages; -2 and 3 specimens tested at 204 C (400 F), type OK-00-125A-A-350 (LEN) gages; -2 and 3 specimens tested at RT, type CEA-00-125UT-350 gages.

* Damaged specimen

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Table 21. Tensile Properties of LARC-160/Celion (0, ±45, 90)S Oriented Postcured Composite(1) (2)

Specimen (4) Number	Test (3) Temperature C (F)	F_{tu} (5) MN/m²	(Ksi)		E_t GN/m²	(MSI)	γ_t	ε Ult μ (%)
EX106-2-1	-132	581	(84.3)			(8.67)	—	0.99 A
-2-2	(-270)	393	(57.0)			(7.55)	0.310	0.79*
-2-3		576	(83.6)			(8.18)	0.330	1.11*
				Avg	56.03	(8.13)	0.320	
EX106-1-1		619	(89.9)			(7.55)	—	1.22* A
-1-2	RT	558	(81.0)			(7.76)	0.280	1.08*
-1-3		528	(76.7)			(7.89)	0.310	1.01*
				Avg	53.28	(7.73)	0.295	
EX106-3-1	204	634	(92.0)			(7.79)	—	1.20 A
-3-2	(400)	544	(79.0)			(8.04)	0.310	0.99*
-3-3		490	(71.1)			(8.18)	0.340	0.86*
				Avg	55.14	(8.00)	0.325	
EX106-4-1	316	604	(87.6)			(7.82)	—	0.90 A
-4-2	(600)	573	(83.1)			(5.20)	0.320	0.96*
-4-3		504	(73.2)			(5.25)	0.280	0.83*
				Avg	41.96	6.09	0.300	

(1) Coupon tensile specimen design necked down test section per Third Quarterly Report. Laminate consisted of 8 ply (0, ±45, 90)S oriented, nominal 0.064 cm (2.5 mils) per ply, Hexcel batch 22796.

(2) Composite Physical Properties:

Density (grams/cc)	Resin Content (%)	Fiber Vol (%)	Void Vol (%)	Thickness Calculated mm	(mils)	Actual Range mm	(mils)	C-Scan Transmission (%)	TMA-Tg (C)
1.588	30.2	62.9	0.47	0.461	(18.1)	0.457-0.503	(18-20)	100	365

(3) Load was applied at 1.27 mm/minute (0.05 inch) after specimens had stabilized at test temperature for 10 minutes. Strain gaged specimens were loaded incrementally to allow for data aquisition.

(4) -1 specimens were tested with a 5.08 cm (2.0 inch) gage length extensometer. Specimens -2 and 3 tested at -132 C and 316 C (-270 F and 600 F) employed type WK-00-125AD-350 gages; -2 and 3 specimens tested at 204 C (400 F), type OK-00-125A-A-350 (LEN) gages; -2 and 3 specimens tested at RT, type CEA-00-125UT-350 gages.

(5) Ftu data points were not averaged since strain gaged specimens were not tested under a constant loading condition.

*** Projected from last strain gage reading**

A Actual

Table 22. Tensile Properties of LARC-160/Celion (0, ±45, 90)$_S$ Oriented Composite, Aged 125 Hours at 316 C (600 F)(1) (2)

Specimen Number (4)	Test (3) Temperature C (F)	F_{tu} MN/m^2	F_{tu} (Ksi)	E_t GN/m^2	E_t (Msi)	γ_t	ϵ Ult μ (%)
EX200TC-1	-132		(71.2)	53.1	7.7		
-2	(-270)		(70.8)	TBD	TBD	TBD	TBD
-3			(66.8)				
	Avg	480	(69.6)				
EX200TC-4			63.1	47.5	6.9		
-5	RT		70.9	TBD	TBD	TBD	TBD
-6			60.0				
	Avg	446	64.7				
EX200TC-7	204		63.3	49.6	7.2		
	(400)			TBD	TBD	TBD	TBD
	Avg	434	63.3		7.2		
EX200TC-8	316		70.9				
-9	(600)		68.1	TBD	TBD	TBD	TBD
-10			74.8	46.1	6.7		
	Avg	491	71.3				

(1) Coupon tensile specimen design necked down test section per Third Quarterly Report. Laminate consisted of 8 ply (0, ± 45, 90)$_S$ oriented, nominal 0.064 cm (2.5 mils) per ply, Hexcel batch 22796.

(2) Composite Physical Properties:

Density (grams/cc)	Resin Content (%)	Fiber Vol (%)	Void Vol (%)	Thickness Calculated mm	Thickness Calculated (mils)	Thickness Actual Range mm	Thickness Actual Range (mils)	C-Scan Transmission (%)	TMA-Tg (C)	Wt. Loss After 125 Hours at 316 C (600 F) %
1.594	31.2	62.0	-0.21	0.465	(18.32)	0.48-0.54	(19-21.5)	100	365	3.2

(3) Load was applied at 1.27 mm/minute (0.05 inch) after specimens had stabilized at test temperature for 10 minutes. Strain gaged specimen data acquisition was obtained autographically on 2 X, Y, Y recorders.

(4) -1 specimens were tested with a 5.08 cm (2.0 inch) gage length extensometer. Specimens -2 and 3 tested at -132 C and 316 C (-270 F and 600 F) employed type OK-00-125AD-350 gages; -2 and 3 specimens tested at 204 C (400 F), type)K-00-125A-A-350 (LEN) gages; -2 and 3 specimens tested at RT, type CEA-00-125UT-350 gages.

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Table 23. Summary of LARC-160/Celion Compression Properties

Panel No.	Fiber Orientation/ Specimen	Compression Property	Test Temperature							
			Postcured				Aged 125 Hours at 316 C (600 F)			
			-132 C (-27°F)	RT	204 C (400 F)	316 C (600 F)	-132 C (-27°F)	RT	204 C (400 F)	316 C (600 F)
EX107	$(0)_t$/	E_{CU} MN/m^2	18.2	1373	1171	880	1667	1529	774	727
(P.C.)	Beam	(Ksi)	(263)	(199)	(170)	(128)	(242)	(222)	(112)	(106)
EX199		E_C GN/m^2	159	155	141	141	151	136	166	157
(Aged)		(Msi)	(23.03)	(20.98)	(20.4)	(20.55)	(22.0)	(19.8)	(24.1)	(22.9)
		ε ULT μ(%)	1.42	1.05	0.960	0.643	1.28	1.29	0.47	0.47
EX93	$(90)_t$/	E_{CU} MN/m^2	231	175	138	92.3	163	157	122	103
(P.C.)	Coupon	(Ksi)	(33.5)	(25.4)	(201)	(13.4)	(23.7)	(22.8)	(177.7)	(15.0)
EX201		E_C GN/m^2	11.8	9.3	7.02	5.79	11.3	8.98	7.37	7.19
(Aged)		(Msi)	(1.71)	(1.35)	(1.02)	(0.841)	(1.65)	(1.30)	(1.07)	(1.04)
		ε ULT μ(%)	2.03	2.17	2.44	2.80	1.64	1.43	1.86	1.83
EX105	$(\pm45)_S$/	E_{CU} MN/m^2	242	182	130	63.5	208	157	138	125
(P.C.)	Coupon	(Ksi)	(35.1)	(26.4)	(18.9)	(9.22)	(30.2)	(22,8)	(20.0)	(18.2)
220		Ec GN/m^2	19.9	15.8	107	10.1	20.8	17.2	14.1	12.7
(Aged)		(Msi)	(2.90)	(2.29)	(1.55)	(1.47)	(3.02)	(2.50)	(2.05)	(1.85)
		ε ULT μ(%)	1.50	3.00	4.17	2,27	1.60	1.47	–	–
EX106	$(0,\pm45,90)_S$/	E_{CU} MN/m^2	720	626	>455	486	548	568	447	442
(P.C.)	Beam	(Ksi)	(105)	(90.8)	>(66.01)	(70.6)	(79.6)	(82.4)	(64.9)	(64.2)
EX200		E_C GN/m^2	61.87	61.39	49.38	56.0	56.4	54.6	48.8	54.0
(Aged)		(Msi)	(8.98)	(8.91)	(7.17)	(8.14)	(8.18)	(7.92)	(7.09)	(7.84)
		ε ULT μ(%)	1.44	1.21	>1.10	1.07	0.96	1.26	1.15	1.06

Table 24. Compressive Properties of $(90)_{40}$ and $(\pm45)_S$ Oriented Fiber LARC-160/Celion Composites

Panel No. / Orientation/ (plies)	Condition (1)	−132°C (−270°F) (2) F_{cu} MN/m^2	F_{cu} (Ksi)	E_c GN/m^2	E_c (Msi)	ε ult (μ) (%)	RT F_{cu} MN/m^2	F_{cu} (Ksi)	E_c GN/m^2	E_c (Msi)	ε ult (μ) (%)
EX98	①		(31.2)		(1.72)	1.86		(23.1)		(1.35)	1.96
(90)/			(35.6)		(1.76)	2.13		(27.3)		(1.39)	2.32
(40)			(33.8)		(1.64)	2.11		(25.7)		(1.32)	2.23
	Avg	231	(33.5)	11.8	1.71	2.03	175	(25.4)	9.3	(1.35)	2.17
EX201	②		(25.2)		(1.64)	1.68		(14.9)		(1.29)	1.19
(90) /			(21.5)		(1.64)	1.66		(18.9)		(1.30)	1.55
(40)			(24.4)		(1.67)	1.59		(19.8)		(1.30)	1.55
	Avg	163	(23.7)	11.3	(1.65)	1.64	157	(22.8)	8.98	(1.30)	1.43
EX91	①		37.7		2.93	1.51		25.3		2.23	2.91
$(+45)_S$/			37.0		2.84	1.76		25.9		2.46	2.30
(32)			30.5		2.94	1.22		27.9		2.18	4.06
	Avg	242	35.1	19.9	2.90	1.50	182	26.4	15.8	2.29	3.00
EX220	②		(28.8)		(3.18)	1.17		(22.1)		(2.56)	1.41
$(\pm45)_S$/			(32.8)		(2.80)	2.45		(23.6)		(2.52)	1.54
(32)			(29.1)		(3.08)	1.18		(22.7)		(2.48)	--
	Avg	208	30.2	20.8	(3.02)	1.60	157	(22.8)	17.2	2.50	1.47

Panel No. / Orientation/ (plies)	Condition (1)	204°C (400°F) (2) F_{cu} MN/m^2	F_{cu} (Ksi)	E_c GN/m^2	E_c (Msi)	ε ult (μ) (%)	316°C (600°F) (2) F_{cu} MN/m^2	F_{cu} (Ksi)	E_c GN/m^2	E_c (Msi)	ε ult (μ) (%)
EX98	①		20.7		1.00	2.46		13.1		0.826	3.00
(90)/			20.1		1.01	2.48		13.7		0.837	2.50
(40)			19.4		1.04	2.37		13.3		0.860	2.90
	Avg	138	20.1	7.02	1.02	2.44	92.3	13.4	5.79	0.841	2.80
EX201	②		--		—	—		(14.2)		(1.06)	1.61
(90) /			—		—	—		(14.6)		(1.01)	1.89
(40)			(17.7)		1.07	1.86		(16.1)		(1.06)	2.01
	Avg	122	(17.7)	7.37	1.07	1.86	103	15.0	7.19	(1.04)	1.83
EX91	①		17.8		1.47	3.49		8.49		1.66	1.89
$(+45)_S$/			19.0		1.40	4.50		9.35		1.11	2.58
(32)			19.8		1.78	4.53		9.82		1.64	2.37
	Avg	130	18.9	107	1.55	4.17	63.5	9.22	10.1	1.47	2.28
EX220	②		(18.6)		(2.07)	--		(19.7)		(1.77)	--
$(\pm45)_S$/			(20.3)		(2.07)	--		(16.7)		(1.73)	—
(32)			(21.2)		(2.01)	—		(18.1)		(2.05)	—
	Avg	138	20.0	14.1	(2.05)		125	(18.2)	12.7	1.85	

Composite Physical Properties (4)	Target properties	EX98	EX91	EX201	EX220
1. Specific gravity (grams/cc)	1.561-1.579	1.598	1.558	1.604	1.589
2. Resin weight content (%)	35.0-31.3	28.4	34.7	30.0	32.5
3. Fiber volume (%)	58-62	65.4	58.1	63.4	59.4
4. Void Volume (%)	<2	-0.29	0.29	0.45	0.90
5. Thickness mm (mils)		1.90-2.05 (75-81)	2.00-2.13 (79-84)	2.48-2.57 (98-101)	1.98-2.08 (78-82)
6. Thickness/ply, mm (mils)	0.0660-0.0609 (2.6-2.4)	0.047-0.051 (1.87-2.0)	0.063-0.067 (2.47-2.63)	.062-.064 (2.45-2.52)	.062-.065 (2.43-2.56)
7. Barcol hardness (ASTM D2583)	>70	75-78	76-79	72-78	73-78
8. Weight loss in postcure (%)	<1	0.15	0.31	--	00.73
9. Weight loss after 125 hrs at 316°C (%)	<1	—	—	0.86	—
10. TMA-Tg C, (F) cured	>330 (626)	330 (626)	352 (666)	—	—
Postcured 4 hours at 316°C (600°F)	>340 (644)	340 (644)	332 (630)	—	349 (660)
Aged 125 hours at 316°C (600°F)	>340 (644)	—	—	359 (678)	
11. C-scan ultra sound transmission (%) (3)					
Cured	>95	100	100	100	100
Postcured 4 hours at 316°C (600°F)	>95	100	100	100	100

(1) Condition ①: Postcured 4 hours at 316°C (600°F); ② aged 125 hours at 316°C, (600°F) for 125 hours.

(2) Specimens were tested after stabilizing at test temperature for 10 minutes at a load rate of 1.27 mm (0.05 inch)/minute in the test fixture shown in the Third Quarterly Report.

(3) NDE ultra sonic through transmission tests were performed using the NASA-LARC established "A" sensitivity standards. C-scan recording for condition ① are reported in the Third Quarterly Report. Condition ② laminate C-scan recording is presented in Figure

(4) Hexcel prepreg batch 22796 used in specimen fabrication; physical properties reported in 4th Quarterly Report. Insitu imidizing—cure cycle per Second Quarterly report used for EX91 & E98 laminates; two stage pre-imidize-cure cycle per Fourth Quarterly Report used for EX201 and E220 laminates.

Space Transportation System
Development & Production Division
Space Systems Group

Rockwell International

Table 25. Flexural Properties of 0° Oriented Fiber LARC-160/Celion Laminates

Panel No./ No. of Plies	Condition(1)	-132°C (-270°F)				RT				204°C (400°F)				316°C (600°F)			
		F_{fu}		E_f		F_{fu}		E_f		E_{fu}		E_f		F_{fu}		E_f	
		MN/m²	(ksi)	GN/m²	(msi)	MN/m²	(ksi)	GN/m²	(msi)	MN/m²	(ksi)	GN/m²	(msi)	MN/m²	(ksi)	GN/m²	(msi)
EX225/ 26	1	–	(296)		(18.9)		(238)		(17.3)		(143)		(19.7)		(161)		(18.4)
		–	(293)		(17.8)		(248)		(18.3)		(152)		(21.4)		(137)		(19.6)
		–	(295)		(18.1)		(241)		(18.0)		(203)		(19.1)		(134)		(19.6)
	Avg	2033	(295)	126	(18.3)	1674	(243)	123	(17.9)	1144	(166)	138	(20.1)	992	(144)	132	(19.2)
EX204/ 26	2		(304)		(19.6)		(254)		(18.0)		(210)		(19.0)		(161)		(17.7)
			(272)		(21.6)		(255)		(19.1)		(220)		(20.1)		(174)		(18.7)
			(255)		(22.2)		(267)		(19.0)		(227)		(18.3)		(176)		(19.4)
	Avg	1902	(276)	145	(21.1	1785	(259)	129	(18.7)	1509	(219)	132	(19.1)	1171	(170)	128	(18.6)

Composite Physical Properties(4)	Target Properties	EX225	EX204
1. Specific gravity (grams/cc)	1.561-1.579	1.581	1.608
2. Resin weight content (%)	35.0-31.3	30.4	30.4
3. Fiber volume (%)	58-62	62.2	63.2
4. Void volume (%)	< 2	0.87	-0.83
5. Thickness mm (mils)	1.716-1.583 (67.6-62.4)	1.47-1.62 (58-64)	1.37-1.54 (54-61)
6. Thickness/ply, mm (mils)	0.0660-0.0609 (2.6-2.4)	0.056-0.062 (2.23-2.46)	0.059-0.053 (2.08-2.35)
7. Barcol hardness (ASTM D2583)	> 70	72-78	73-74
8. Weight loss in postcure (%)	< 1	0.22	-
9. Weight loss after 125 hr at 316°C (°F)		-	1.03
10. TMA-Tg °C, (°F) cured	> 330 (626)	-	-
Postcured 4 hours at 316°C (600°F)	> 340 (644)	353 (667)	-
Aged 125 hours at 316°C (600°F)	> 340 (644)	-	365 (689)
11. C-scan ultra sound transmission (%)(3)			
Cured	> 95	100	100
Postcured 4 hours at 316°C (600°F)	> 95	100	100

(1) Condition 1 : Postcured 4 hours at 316°C (600°F); 2 aged 125 hours at 316°C (600°F)

(2) Specimens were tested after stabilizing at test temperature for 10 minutes at a load rate of 1.27 mm (0.05 inch).

(3) NDE ultra sonic through transmission tests were performed using the NASA-LaRC established "A" sensitivity standards. C-scan recordings for Condition 1 are reported in the Third Quarterly Report. Condition 2 laminate C-scan recordings are presented in Figure .

(4) Hexcel prepreg batch 22796 used in specimen fabrication; physical properties reported in Fourth Quarterly Report. The two stage preimidizing-cure cycle specified in the Fourth Quarterly Report was employed in laminate fabrication.

Table 26 Short Beam Shear Properties of 0° Oriented Fiber LARC-160/Celion Laminates

Panel No./ No. of Plies	Condition (1)	-132°C (-270°F)		RT		204°C (400°F)		316°C (600°F)	
		F_{su}		F_{su}		F_{su}		F_{su}	
		MN/m^2	(ksi)	MN/m^2	(ksi)	MN/m^2	(ksi)	MN/m^2	(ksi)
EX204/ 26	2		(19.0) (19.7) (20.9)		(17.1) (17.6) (17.5)		(12.6) (12.8) (12.6)		9.3 9.3 8.8
	Avg	137	(19.9)	120	(17.4)	86.8	(12.6)	63.4	(9.2)
EX225/ 26	1		(21.1) (23.9) (22.9)		(17.9) (18.3) (17.7)		(12.8) (12.9) (12.0)		(8.9) (8.5) (8.1)
	Avg	156	(22.6)	124	(18.0)	86.8	(12.6)	58.5	(8.5)

Composite Physical Properties (4)	Target Properties	EX225	EX204
1. Specific gravity (grams/cc)	1.561-1.579	1.581	1.608
2. Resin weight content (%)	35.0-31.3	30.4	30.4
3. Fiber volume (%)	58-62	62.2	63.2
4. Void volume (%)	<2	0.87	-0.83
5. Thickness mm (mils)	1.716-1.583 (67.6-624)	1.47-1.62 (58-64)	1.37-1.54 (54-61)
6. Thickness/ply, mm (mils)	0.0660-0.0609 (2.6-2.4)	0.059-0.062 (2.23-2.46)	0.059-0.053 (2.08-2.35)
7. Barcol hardness (ASTM D2583)	>70	72-78	73-74
8. Weight loss in postcure (%)	<1	0.22	—
9. Weight loss after 135 hours at 316°C (%)		—	1.03
10. TMA-Tg C, (F) cured	>330 (626)	—	—
Postcured 4 hours at 316°C (600°F)	>340 (644)	353 (667)	—
Aged 125 hours at 316°C (600°F)	>340 (644)	—	365 (689)
11. C-scan ultra sound transmission (%)(3)			
Cured	>95	100	100
Postcured 4 hours at 316°C (600°F)	>95	100	100

(1)Condition 1: Postcured 4 hours at 316°C (600°F); 2 aged 125 hours at 316°C (600°F)
(2)Specimens were tested after stabilizing at test temperature for 10 minutes at a load rate of 1.27 mm (0.05 inch)/minute.
(3)NDE ultrasonic through transmission tests were performed using the NASA-LaRC established "A" sensitivity standards. C-scan recordings for Condition 1 are reported in the Third Quarterly Report. Condition 2 laminate C-scan recordings are presented in Figure .
(4)Hexcel prepreg batch 22796 used in specimen fabrications, physical properties reported in Fourth Quarterly Report. The two stage preimidizing cure cycle specified in the Fourth Quarterly Report was employed in laminate fabrication.

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Table 27. Structural Element Weight Losses After Aging at 316 C (600 F) for 125 Hours.

Configuration	Specimen No.	Initial Wt. (grams)	Wt. Loss %
"HAT"	EX195-2A	349.1	1.43
	EX195-3A	348.0	1.39
	EX195-4A	343.8	1.45
"I"	EX194-2A	399.6	1.25
	EX194-3A	398.2	1.36
	EX194-4A	395.1	1.27
Sandwich	EX241-2A	—*	0.75
	EX241-3A	—	0.72
	EX241-4A	—	0.72

*Not comparable—doublers are bonded to panel ends.

Table 28. Structural Element Potting Materials and Processes.

Test Temperature	Potting Material	Process (1)
-132 C (-270 F)	Filled epoxy paste, EA934, Hysol Corporation	1. Mix, pot & cure at R.T, 4 hours. 2. Post cure at 121 C (250 F) for 2 hours.
RT	Filled epoxy paste, EA911-11, Hysol Corporation	1. Mix, pot and cure at R.T., 8 hours minimum
316 C (600 F)	Aluminum filled polyimide resin, BR 34B-18, American Cyanamid Corporation	1. Modify base material by adding 35% - 0.8 mm (1/32 in) fiberglass milled fibers. Mix on paint shaker for 30 minutes minimum. 2. Pot specimen ends with Compound approximately 10.16 mm (0.40 inch) deep. 3. Place in oven and raise temperature R.T. to 177 C (350 F) at < 1.1 C (2 F)/min. 4. Raise temperature 177 C (350 F) to 316 C (600 F) at < 1.7 C (3 F)/min. 5. Post cure at 316 C (600 F) for 2 hours.

(1) Alignment of all specimens during cure was maintained within machined tolerance by clamping to right angle fixtures.

Table 29. Structural Element Target Loads

Specimen Design	Design Ult. Load, KN/cm (lbs/inch) Test Temperature C (F)		
	-132 (-270 F)	RT	316 C (600 F)
"Hat" Stringer	528 (3016)	528 (3016)	319 (1819)
"I" Stringer	542 (3016)	542 (3096)	325 (1858)
Sandwich	805 (4600)	805 (4600)	483 (2760)

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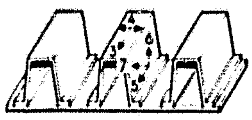
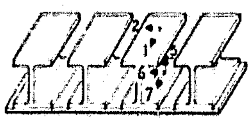
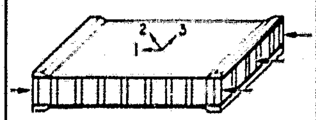
Table 30. Results of Compression Tests on "Hat" and "I" Stiffened Skin and Sandwich Panel Structural Elements(1)

Element Configuration	Condition(2)	Element No.	Test Temperature C	(F)	Ultimate Load KN	(LBS)	Remarks
 STRAIN GAGES 1 AND 2 INSTALLED ON LOWER SKIN DIRECTLY OPPOSITE 3 AND 4	1	EX109/EX110A	24	(75)	120.8	(27,150)	Achieved design ultimate, compressive failure of hat caps with transfer thru webs occurred during strain gage readout at 27,150 lbs. Skin and bond failures were secondary.
		EX109/EX110B	24	(75)	120.8	(27,150)	Achieved design ultimate - no failure. Specimen was then fatigue tested 5% to 67% of design ultimate, compression/compression load to 265,000 cycles - no failure.
		EX109/EX110B	-132	(-270)	116.8	(26,250)	Skin compression failure - load dropped to 19,500 lbs. Retest of EX109/EX110B specimen tested at RT. Failed at 97% of design ultimate.
		EX195-1 PC	316	(600)	87.84	(19,750)	Skin compression failure, bottom 2 corners followed by buckling through bottom-center. Minor bond failure, center stringer under skin buckle. 73% of RT design ultimate.
	2	EX195-2A	24	(75)	120.8	(27,150)	Achieved design ultimate - no failure.
		EX195-4A	-132	(-270)	120.8	(27,150)	Achieved design ultimate - no failure.
		EX195-3A	316	(600)	124.3	(27,950)	Skin compression failure inboard of 1 bottom corner followed by diagonal skin buckling toward center of panel. Minor debond under center stringer. Failed at 103% of RT design ultimate.
 STRAIN GAGES 3 AND 4 INSTALLED ON LOWER SKIN OPPOSITE 1 AND 2	1	EX111/EX113	24	(75)	125.4	(28,187)	Achieved design ultimate - no failure.
		EX111/EX113	-132	(-270)	125.4	(28,187)	Achieved design ultimate - no failure. Retest of EX111/EX113 tested at RT.
		EX111/EX113	24	(75)	125.4	(28,200)	Achieved design ultimate - no failure. Retest of EX111/EX113 tested at RT and -270 F.
		EX194-1 PC	316	(600)	125.4	(28,187)	Achieved design ultimate - minor skin compression failure in 1 corner. Did not cause drop in load. No debonds.
	2	EX194-2A	24	(75)	125.4	(28,187)	Achieved design ultimate - no failure.
		EX194-4A	-132	(-270)	125.7	(28,250)	Achieved design ultimate. Compression failure of skin starting at 1 upper corner extends inboard 1 inch. Two stringer caps and webs also failed in compression with caps splitting axially. No debonds.
		EX194-3A	316	(600)	125.4	(28,187)	Achieved design ultimate - no failure.
 STRAIN GAGES 4, 5, AND 6 INSTALLED ON LOWER SKIN OPPOSITE 1, 2, AND 3	1	EX150-1	24	(75)	125.7	(28,260)	Achieved required 0.53 MN/m (3000 lbs/inch) compression load. Skin compression failures occurred along edges of bottom doublers. No debonds.
		EX241-1PC	-132	(-270)		TBD	
		EX150-2	316	(600)	97.86	(22,000)	Skin compression 1 side only, top corner, 1.12 inch above doubler at edge, extends 3.0 inches inboard. Achieved 81% of RT requirement of 0.53 MN/m (3000 lbs/inch). No debonds.
	2	EX241-2A	24	(75)		TBD	
		EX241-4A	-132	(-220)		TBD	
		EX241-3A	316	(600)		TBD	

(1)Specimen designs are given in 2nd and 3rd quarterly reports. Load/Strain curves are presented in Figures 65 through 79
(2)Condition 1 : Postcured 4 hours at 316 C (600 F); 2 aged 125 hours at 316 C (600 F)

Table 31. Physical Properties of Celion/LARC-160 Composite Laminates Delivered to NASA-LaRC, Tasks (d) and (f)(1)

Properties / Panel No./No. Plies-Orientation	Target Property	CL6C-11/ 6-($\pm$45,90)$_S$	CL12C-6/ 12-($\pm$45,90)$_S$	CL24C-7/ 24-($\pm$45,90)$_S$	CL12C-8/ 12-(0,90)	CL12C-9/ 12-(0,90)
Composite Physical Properties(1)						
1. Specific gravity (grams/cc)	1.561-1.579	1.565		1.587	1.567	1.560
2. Resin weight content (%)	35.0-31.3	34.5		30.3	31.7	35.2
3. Fiber volume (%)	58-62	57.91		62.5	60.5	57.1
4. Void Volume (%)	<2	0.56		0.51	1.32	0.65
5. TMA-Tg C, (F)						
Postcured 4 hrs at 316 C (600 F)	>340 (644)	361 (682)	348 (658)	344 (651)	341 (646)	344 (651)
6. C-Scan ultra sound transmission (%(						
Cured	>95	98	99	97	98	100
Postcured 4 hrs at 316 C (600 F)	>95	98	99	97	98	100

(1)Hexcel prepreg batch 23091, Roll 1 was used in fabrication of all laminates; physical properties are as follows: Fiber areal weight: 127 grams/m^2; calculated thickness/ply: 0.122 mm (4.80 mils); resin solids content: 37.4%; volatile content: 12.5%

TABLE 32

CELION/LARC-160 PROGRAM-NAS1-15371

VARIABLE STUDY-REPEATABILITY, STORAGE AND OUT-TIME ANALYSIS

PREPREG BATCH 4.5 Kg (10 Lb.) Ea.	FORMULATION & PROCESSING	RESIN ANALYSIS		PREPREG ANALYSIS		STORAGE AND OUT-TIME EVALUATION					
									Out-Time		
		Int. Ester	Neat Resin	Resin Extract	Prepreg & Lam. Properties	1 Mo.	3 Mo.	6 Mo.	1 Mo. Mat'l	3 Mo. Mat'l	6 Mo. Mat'l
1	within limits defined by study (a-2)	X	X	X, X_1, X_3, X_6	X, X_1, X_3, X_6	X_1	X_3	X_6	X_1	X_3	X_6
2		X	X	X, X_1, X_3, X_6	X, X_1, X_3, X_6	X_1	X_3	X_6	X_1	X_3	X_6
3		X	X	X, X_1, X_3, X_6	X, X_1, X_3, X_6	X_1	X_3	X_6	X_1	X_3	X_6

1. Number of batches reduced and batch size increased from 1.35 Kg(3 lb.) to 4.5 Kg(10 lb.) in order that prepreg may be produced under production, rather than laboratory, conditions.

2. Start of run for all three batches, as measured from introducing resin into holding container to start of impregnation, shall not vary from batch-to-batch by more than (TBD) minutes.

APPENDIX A

DETAILED PROCESSING FOR FABRICATING FLAT LAMINATES AND HAT-SECTION/"I" BEAM STRINGERS

1.0 FLAT LAMINATE FABRICATION PROCESSING

1.1 PREPREG TAPE LAYUP PROCEDURES

Stack prepreg tape in the required ply orientation and number of plies, paper backing surface up, on a smooth tooling surface such as a glass plate. Supporting layup materials such as parting films, bleeders, porous teflon coated 104 fiber glass (TX1040 or 3TLL), caul plate, breathers and vacuum bag are shown in the layup sequence in Figure A1.

During layup, it is preferable to slice the edges of the tape using a straight edge in order to remove irregularities. If the prepreg tape edges are cut clean and uniform, this operation can be omitted. Normally, the Celion/LARC 160 tape will have adequate tack to adhere to itself, however, if tack is not adequate a hot iron may be employed to aid layup. This is accomplished by ironing directly over the paper backing; either locally tacking or flat ironing to adhere the plies. The iron heat setting should be in the range of 176 C (350°F). Great care shall be exercised in insuring either absolute butt joints or a slight overlap of 0.76 mm (0.03 inch) in the layup of tape elements. Tow splices should be flagged on the tape roll by the supplier, however, extreme care shall be taken to visually inspect each tape element. Any sections having tow splices must be removed.

1.2 DEBULKING PROCEDURE

Debulking of stacked prepreg has been found to be advantageous in fabricating both flat and complex shaped laminates for the following reasons:

- Preconsolidation debulks the prepreg close to final laminate thickness; therefore, when augmented pressure is applied during final cure, less resin and fiber movement is required to achieve ultimate thickness.

- During the debulking operation, supporting materials such as TX1040 and bleeders are adhered to the laminate stack, forming a well consolidated unit that is easily handled during subsequent operations.

- Prestacked and debulked laminates are easily stored, under refrigeration, in sealed bags.

- The preconsolidated preforms, with bleeder materials in-place, are easily handled in vacuum forming operations during the fabrication of hat, "I", "pi" and other complex shape elements.

- Where dry prepreg is used in the layup, the debulking operation not only consolidates and adheres the materials but also rejuvenates the resin tack, making the total stack pliable.

Two approaches to the flat laminate debulking operations have been developed and successfully qualified for use in Tasks (a), (b), (c), (d), (e) and (f).

1.2.1 Dry Prepreg Debulking

The following operations are to be performed after completing the stacking operations described in 1.1 and Figure A1.

- Select a flat, 4.6 - 6.35 mm (0.18 - .0.25 inch), aluminum caul plate the same size as the stacked layup.

- Apply Frekote 33 mold release to the caul surface which will face the layup.

- Preheat the caul plate to 127 ± 6.6 C (260 ± 12°F)

- On removal from the oven (within 2 - 3 minutes), immediately assemble the caul plate to the stacked layup surface, seal in a vacuum bag and apply vacuum to > 67 KN/m^2 (>20 inches Hg).

  Note: The layup area shall have been previously prepared for rapid vacuum bag application so that minimal heat loss is incurred from the hot caul plate. This operation softens the LARC-160 resin and causes it to flow into the TX1040 and bleeder materials, creating a consolidated prepreg/bleeder preform. The dry prepreg stack will become mildly tacky and pliable after this operation.

- Allow the assembly to stabilize to room temperature before removing the vacuum bag.

1.2.2 Tacky Prepreg Debulking

The same procedures shall be employed as in 1.2.1, except that heating of the caul plate is optional. If heat is used, the procedure described in 1.2.1 shall be followed. The layup shall be debulked at room temperature under vacuum bag pressure, <67 KN/m^2 (<20 inches Hg) for a minimum of four hours.

1.3 IMIDIZING PROCEDURE

Principal concerns with the LARC-160 polyimide resin/graphite materials are ensuring (1) efficient, uniform removal of solvent and condensation reaction volatiles from large and complex surface areas, and (2) resin flow control in the composite prior to application of augmented pressure during the cure cycle.

Prepreg volatile removal techniques were developed in Task (b), Process Development, with use of techniques and tooling shown in Figure A2. The concept of uniform removal of volatiles is based on use of a perforated layup tool surface. Perforations in the surface act as individual, unrestrained vacuum ports serving local surface areas of about one square inch. Vacuum channel separator strips

are located in-line between the vacuum ports to support the caul layup surface and to provide an unrestrained venting system to a central manifold that, in turn, leads to the main vacuum source.

The laminate preform is imidized on porous tooling shown in Figure A2. The laminate is contained in a Celgard[1] 4500 or 4510 polypropylene microporous membrane which allows removal of volatiles through the bottom perforated caul plate while preventing resin loss into surronding breathers. Volatiles are reduced to less than 3 percent by this procedure. The imidizing cycle is shown in Figure A3.

A perforated top pressure caul without vacuum channels may be used, rather than a perforated bottom plate, if desired, although this concept has not been proved for larger, thicker, laminates. If the top perforated caul is used, efficient methods for venting volatiles to the vacuum source must be employed.

1.3.1 Detailed Imidizing Procedure

- Apply one-7781 fiberglass breather ply and one layer of Celgard 4500 or 4510 to the surface of the perforated lay up plate as shown in Figure A2. Celgard may be spliced with an electronic heat sealer or with a thin band of Kapton tape 6.35 mm (0.25 inch).

- Transfer the debulked preform, with integral bleeders, prepared per 1.2, from the layup tool to the prepared perforated layup plate.

- Assemble all bagging components per Figure A2 and install thermocouples in the trim edge of the part per Engineering direction.

- Install the assembly in an air circulating oven and perform the imidizing cycle per Figure A3. Thermocouples placed within the part trim, not oven temperature, shall be used in controlling the imidizing cycle. Thermocouple data shall be autographically recorded.

1.4 CURE PROCEDURE

Imidized flat laminates are autoclave cured on tooling shown in Figure A4. Since the laminate volatile content has been reduced to < 3% during the imidizing procedure it can now be treated analgous to an epoxy laminate in the cure process. Nonperforated cauls are employed with the bleeder arrangement shown in Figure A4. The autoclave cure cycle is shown in Figure A5.

Process development, performed during Task (b) and verified in Tasks (a), (b), (c), (d), (e), and (f), has shown that considerable latitude exists in cure cycle temperature heat rise rates, ultimate cure temperatures and pressure levels. For example, ultimate cure temperature and pressure can be accomplished as low as 274°C (525°F) and 689 KN/m^2 (100 psi) respectively (Reference 2nd quarterly report). At this time, minimum cure temperature has been set at 287°C (550°F) and pressure 1378 KN/m^2 (200 psi).

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(1) Celgard microporous membrane films are manufactured by the Celenese Plastics Company, Morris Court, Summit, N.J. 07901.

Autoclave pressurization rates evaluated have been in the 5 to 7 minute range from 0 to 1378 KN/m^2 (0 to 200 psi). The pressure application window appears to be optimum in the temperature range of 274 to 287°C (525 to 550°F). Resin hot melt flow is in the range of 254 to 265°C (490 to 510°F), however, the apparent viscosity is very low. If pressure is initiated before 274°C (525°F) excessive resin losses have been realized, resulting in high fiber volume laminates.

Laminates are post cured at 316 C (600°F) for 4 hours in an air circulating oven in free standing position. Postcuring studies during Task (b) proved that the composite Tg is significantly increased and mechanical properties at 316 C (600°F) are improved. Regardless of Tg or mechanical properties values attained after initial cure, post cure of all laminates has been specified to insure retention of laminate quality after exposure to the operating service temperatures.

1.4.1 Detailed Autoclave Curing Procedure

- Remove the Celgard membrane from the bottom surface of the laminate, being careful not to damage or disturb the imidized layup. Leave the 2.3 to 4.8 mm (0.09 to 0.18 inch) top pressure caul in place; do not remove bleeder.

- Transfer the laminate to the steel curing tool (nonperforated surface). The steel tool surface shall be prepared using Frekote 33 parting agent. A Kapton glide sheet shall be employed to separate the laminate from the tool surface. Tape all components in place with Kapton pressure sensitive tape.

- Install type 162 fiberglass breathers (or equivalent) over the aluminum pressure caul and onto the tool surface. Adequate breather material shall be placed between the part and vacuum source to insure efficient removal of any residual volatiles.

- Install thermocouples into the edge of the part in areas designated by engineering personnel. These thermocouples shall be used in monitoring and recording time/temperature data during cure and shall be used to control the cure cycle.

- Install a 0.051 mm (0.002 inch) thick Kapton film bag over the breather and tool surfaces and seal around the periphery of the tool using G.S.43[(2)] sealant or equivalent. Insure that no bridges exist or sharp protrusions bear against the vacuum bag. Make vacuum bag "ear" seals as required to insure adequate bag slack to prevent bridging.

- Install the steel clamping ring and secure with bolts around the periphery of the tool. The complete tooling arrangement is shown in Figure A4.

- Install the tooling in an autoclave and apply full vacuum to the tooling system. Apply 100 psi to the autoclave and inspect the system for leaks. If a vacuum leak greater than 33.6 KN/m^2 (10 inches Hq) occurs within 5 minutes, the source shall be located and repaired.

[(2)] G.S. 43 sealant may be purchased from General Sealants Co., Los Angeles, California.

- Perform the cure cycle within the time temperature profile of Figure A5. Record all events such as application of various levels of vacuum, pressure and autographically record temperature from each thermocouple on parts and autoclave. The part thermocouples shall be used in controlling the cure cycle. All part temperatures shall be in the range of 274 to 287°C (525°F to 550°F) when 1378 KN/m^2 (200 psi) autoclave pressure is applied.

- Remove bleeder materials and clean up parts.

- Submit to Quality Engineering for NDI C-scan test.

1.5 POSTCURE PROCEDURE

- Postcure in an air circulating oven by raising the oven and part temperature from R.T. to 316°C (600°F) at an average heat rise rate of 1.6 to 8.3 C (3 to 15°F)/minute and hold at 316 C (600°F) for 4 hours.

2.0 "I" STRINGER FABRICATION PROCESSING

Stock for the individual components of the "I" stringer ("C" channels, caps and radius fillets) are laid up and debulked as flat laminates per paragraphs 1.1 and 1.2 and then vacuum formed and imidized on tooling shown in the fabrication flow charts, Figures A6 and A7. Vacuum forming of "C" channel and bottom surface top cap flat preforms enables easy wrinkle free shaping of components.

Preformed imidized radius fillets that fill the interstices between "C" channels and caps to near net shape and cap elements are easily handled and located in position during assembly for autoclave cure.

2.1 "I" STRINGER TOOLING DESCRIPTION

The tooling concept is shown in Figure A6.

- "C" channel mandrels are fabricated from 6061T6 or equivalent aluminum alloy.

- The $(0)_7$ bottom surface top cap forming mold is comprised of a molded SMC 250 silicone rubber(1) pressure caul stabilized on an aluminum bar. The rubber caul is fabricated as shown in the fabrication flow chart Figure 6.

- Imidizing tooling for the top cap preform is comprised of a perforated layup plate and solid pressure caul.

- Tooling for preforming and imidizing the 0° fillet stock is shown in Figure A7.

2.2 LAYUP AND DEBULKING PROCEDURES

- Layup flat stock for "C" channels, $(\pm 45)_s$, 4 ply; $(0)_7$ top cap; $(0)_7$ bottom surface top cap; and $(0)_5$ fillet elements per design requirements. Follow the layup and debulking procedures described in paragraph 1.1 and 1.2. For this "I" beam design, nominal 152 $\pm$ 4 gram/m^2 areal fiber weight prepreg having a nominal 0.145 mm (5.7 mil) cured ply thickness was used. During the layup procedure, the TX1040 and bleeder materials where applied to "C" channels must be laid on a 45° bias to the rectangular flat preform. This is required to prevent wrinkling during preforming and imidizing operations.

(1) SMC 250 rubber is a product of "D" Aircraft Products, Anaheim, California

- For layup of the flat stock for the fillet elements, any of the three areal fiber weight prepreg materials purchased for the program could be used. The table below shows the number of 0° plies required for the different materials.

Fiber Areal Weight (grams/m^2)	Calculated Thickness/Ply mm (mils)	No. of Plies
152 ± 4	0.145 (5.7)	5
134 ± 3	0.127 (5.0)	6
67 ± 3	0.064 (2.5)	12

2.3 VACUUM FORMING "I" STRINGER ELEMENTS

The "I" stringer elements; "C" channels, bottom surface top cap and fillets are vacuum formed prior to imidizing.

2.3.1 Bottom Surface Top Cap

- Apply Frekote 33 parting agent to the aluminum "C" channel mandrels surfaces and oven dry for 15 minutes at 176°C (350°F)
- Assemble two "C" channels together with attachment bolts
- Cut a 3.5 cm (1.48 inch) wide, 96.5 cm (38.0 inch) long strip of debulked $(0)_7$ ply prepreg stock. Remove TX1040 and bleeder ply.
- Assemble the $(0)_7$ layup to the "I" beam mold top cap surface, between two edge dams as shown in Figure A6.
- Place the SMC 250 silicone rubber surfaced aluminum pressure caul in place over the layup.
- Apply a breather and nylon film vacuum bag, seal and place in an autoclave. Apply > 84 KN/m^2 (> 25 inches Hg) vacuum and 689 KN/m^2 (100 psi) pressure. Raise the temperature to 65°C (150°F) and hold for 15 minutes. Force cool to room temperature.
- Remove the tooling from the bag.
- Cut the preformed laminate along the center line of the cap cleavage to separate the two mandrels. The cap $(0)_7$ preforms will adhere to each "C" mandrel after this operation. These remain in place for vacuum forming the "C" channels. Remove TX1040 from laminate.

2.3.2 "C" Channels

- Prepare a flat plate of suitable size for holding each "C" channel mandrel in a vacuum bag. Vacuum bag materials and seals shall be prepared previously so that a rapid seal can be made in the subsequent vacuum forming operation.

- Cut a 12.7 cm (5 inch) wide, 96.5 cm (38.0 inch) long strip of debulked $(\pm 45)_S$, 4 ply prepreg stock. Remove the TX1040 faying with the laminate surface facing the tool.

- Place the mandrel on the flat plate. Transfer the debulked laminate with integral ($\pm$ 45) TX1040 and 1 ply 120 bleeder to the mandrel and secure in place on the ends with a small piece of adhesive tape.

- Drape the vacuum bag over the flat-debulked laminate on the mandrel, seal and draw vacuum. This operation will form the laminate with TX1040 and bleeder in place, over the "C" channel, wrinkle free.

- Place the assembly in an air circulating oven and raise the mandrel and part temperature to 65 to 93°C (150 to 200°F) and hold for 15 minutes.

- Allow the assembly to return to room temperature before releasing vacuum. The laminate preform, with integral 45° bias bleeders and porous TX1040 separators will remain secured to the mandrel and is now ready for imidizing operations.

2.4 "I" STRINGER ELEMENT IMIDIZING PROCEDURE

2.4.1 "C" Channels

- Drape a layer of Celgard 4500 or 4510 microporous membrane over the preform bleeder surface and secure in place, wrinkle free with pressure sensitive tape on the backside of the mandrel. Celgard is used to contain the resin and release volatiles during imidization.

- Place the two "C" channel mandrels on a flat plate suitable for applying a vacuum bag.

- Install thermocouples under the breather material over the part, outside trim lines. Data from thermcouples shall be autographically recorded and used as the basis for controlling the imidizing cycle. Thermocouple placement shall be by engineering direction.

- Drape one ply of type 120 or 7781 fiberglass or Mockburg paper breather material over the Celgard film surface.

- Install a nylon film vacuum bag, drape in place over the preform bleeder surface and seal around the periphery of the flat aluminum plate. Insure that an efficient breather system such as multi plies of type 162 fiberglass breather are connected between the parts and vacuum source. The "C" channel imidizing arrangement is shown in Figure A6.

- Place the bagged assembly in an air circulating oven and imidize per Figure A3. Monitor and record thermocouple and other cycle events such as vacuum data.

2.4.2 Fillets

The fillet imidizing tooling and molding concept is shown in Figure A7. The tooling is designed to augment vacuum bag pressure through a pressure augmenter plate to a maximum of 710 KN/m^2 (103 psi) when 101 KN/m^2 (30 inches Hg) vacuum is applied. This feature produces well defined and consolidated preimidized fillet preforms.

- For each fillet preform, cut a 6.35 mm (0.25 inch) wide strip from the debulked fillet stock, remove TX1040 and bleeder, and place the strip in the fillet preform tool cavity.

- Install dams and pressure mandrels, thermocouples, pressure augmenter plate, breathers, vacuum bag, and seal per Figure A7.

- Place the assembly in an air circulating oven and imidize per Figure A3. Thermocouple data shall be used for controlling the imidizing cycle and shall be recorded autographically.

2.4.3 Top Cap $(0)_7$

Imidize top cap and layup per 1.3.1.

2.5 ASSEMBLY OF "I" BEAM ELEMENTS

- Remove Celgard, TX1040, and bleeder materials from outside surfaces of imidized "C" channel elements. Care shall be exercised to prevent damage to imidized preforms.

- Join the two "C" channel mandrels together with undersize diameter fasteners to allow for mandrel movement while under pressure during cure.

- Install two imidized 0° fillet elements in cleavage, top and bottom, between the "C" channels and secure in place at part ends, outside the part trim area, with a small piece of Kapton tape.

- Install tooling dams on top cap edges.

- Place the assembly on a flat steel tool for autoclave curing at 329°C (625 F), 1378 KN/m^2 (200 psi). The tool surface shall be prepared by coating with Frekote 33 parting agent. Cover tool surface with Kapton film glide sheet.

- Cut a 3.5 cm (1.48 inch) wide, 96.5 cm (38.0 inch) long strip of imidized (0), 7 ply laminate stock and remove TX1040 and bleeder materials.

- Place the laminate in the top cap recess over the $(\pm 45)_s$, 4 ply flanges of the "C" channels and (0°) fillet elements.

- Install the top pressure caul. The pressure caul shall be prepared by coating with Frekote 33 parting agent.

- Install type 162 fiberglass breathers (or equivalent) over the "I" beam tooling and onto the tool surface. Adequate breather material shall be placed between the part and vacuum source to insure efficient removal of volatiles and protection of the bag.

- Install thermocouples into the edge of the part in areas designated by engineering personnel. These thermocouples shall be used in monitoring and recording time/temperature data during cure and shall be used to control the cure cycle.

- Install a 0.051 mm (0.002 inch) thick Kapton film bag over the breather and tool surfaces and seal around the periphery of the tool using G.S. 43 sealant or equivalent. Insure that no bridges exist or sharp protrusions bear against the vacuum bag. Make vacuum bag "ear" seals as required to insure adequate bag slack to prevent bridging.

- Install the steel clamping ring and secure with bolts around the periphery of the tool.

2.6 AUTOCLAVE CURE PROCEDURE

- Install the tooling in an autoclave and apply full vacuum to the tooling system. Apply 100 psi to the autoclave and inspect the system for leaks. If a vacuum leak greater than 33.7 KN/m^2 (10 inches Hg) occurs within 5 minutes, the source shall be located and repaired.

- Perform the cure cycle within the time temperature profile of Figure A5. Record all events such as application of various levels of vacuum, pressure and autographically record temperature from each thermocouple on parts and autoclave. The part thermocouples shall be used in controlling the cure cycle. All part temperatures shall be in the range of 274 to 287°C (525°F to 550°F) when 1378 (KN/m^2) (200 psi) autoclave pressure is applied.

- Remove bleeder materials and clean up parts.

- Submit to Quality Engineering for NDI C-scan test.

2.7 POSTCURE PROCEDURE

Postcure the "I" beam in an air circulating oven by raising the oven and part temperature from room temperature to 316°C (600°F) at an average heat rise rate of 1.6 to 8.3°C (3 to 15°F)/minute and hold at temperature for 4 hours. The "I" beam shall be supported on a flat base, free standing, during postcure.

3.0 HAT-SECTION STRINGER FABRICATION PROCESSING

Stock for the individual components of the hat-section stringer are laid up and debulked as flat laminates per paragraphs 1.1 and 1.2 except for modifications noted herein. Only the $(0)_{16}$ unidirectional cap reinforcement is imidized in accordance with paragraph 1.3. Imidization of the web/flange components is accomplished in situ during the autoclave cure cycle.

Layup of the hat-section stringer for autoclave cure is as shown in Figure A8.

3.1 HAT-SECTION STRINGER TOOLING DESCRIPTION

The tooling concept is shown in Figure A8.

- The mandrel shall be reverse formed 6.3 mm (0.25 inch) at the midpoint of the 127 cm (50 inches), concave to the cap. This operation is required to offset warping which occurs convex to the hat surface when cure is accomplished on a flat tool. Reference Section 3.3.4.1 in the text.

- External hat surfaces are molded with a SMC 250 flexible silicone rubber caul. Processing technology developed in Task (b) involving the use of flexible rubber cauls was implemented in order to mold smooth external surfaces on the hat elements, reference 3rd Quarterly Report. This required modifying the LARC-160 cure cycle (in Task B) by reducing the cure temperature to 287°C (550°F) maximum in order to preserve the rubber for multiple cure cycles. The rubber selected was DAPCO-SMC 250 silicone stock, supplied in an uncured continuous calendered sheet form 1.5 mm (0.06 inch) thick.

- Application of Kapton film vacuum bag and supporting materials is as described in Sections 1.0 and 2.0.

3.2 LAYUP AND DEBULKING PROCEDURE

- Prepreg tape having a nominal 0.145 mm (5.7 mil) cured ply thickness and 152 ± 4 grams/m^2 areal fiber weight was used for this hat-section stringer design.

- Flat laminate stock, $(0)_{16}$ was laid up and debulked per paragraphs 1.1 and 1.2 for the hat-section cap.

- Two flat laminates, ($\pm$ 45) 2 ply, for inner and outer web/flange elements of the hat-section were laid up and debulked per paragraphs 1.1 and 1.2. However, the laminate stock for the inner element was debulked without bleeder material. In the layup of the laminate stock for both inner and outer elements, the TX1040 only and TX1040 with bleeder were

applied to the laminate surface (as determined by the assembly) on a 45° bias to the rectangular laminate shape to prevent wrinkling during vacuum forming.

3.3 $(0)_{16}$ CAP IMIDIZING PROCEDURES

- The $(0)_{16}$ cap stock is imidized per 1.3 except that 179 KN/m^2 (25 psi) is applied after the 115 C (240°F) cycle to increase compaction and to reduce material movement during the cure process and thereby eliminate wrinkles in the cap area, refer to section 3.3.4 in the text.
- The cap element laminate stock thickness shall be < 2.9 mm (< 0.115 inch).
- If several "hat" elements are to be fabricated it is recommended that enough cap stock is laid up and imidized to satisfy the total requirement.

3.4 SHAPING THE $(0)_{16}$ CAP ELEMENT

- Trim a 2.79 cm (1.1 inch) wide strip from the imidized $(0)_{16}$ laminate stock parallel to the fibers using a sharp knife and straight edge. Remove TX1040 and bleeder.
- Place the strip on the top of the mandrel and bevel the edges to match the angle of the tool using a sanding block.

3.5 VACUUM FORMING AND ASSEMBLY PROCEDURES

- Apply Frekote 33 parting agent to the hat-section mandrel surfaces and oven dry for 15 minutes at 176°C (350°F).
- Cut a 15.2 cm (6.0 inches) wide strip from the debulked 2 ply ($\pm$ 45) flat laminate (inner element) to desired length for the inner layer of the hat-section.
- Prepare a flat plate of suitable size for holding the mandrel in a vacuum bag. Vacuum bag materials and seals shall be prepared previously so that a rapid seal can be made in the subsequent vacuum forming operation.
- If the prepreg is dry and nontacky, heat the hat-section mandrel to 65 $\pm$ 6°C (150 $\pm$ 10°F) to promote improved drape for vacuum forming.
- Place the mandrel on the prepared flat plate. Transfer the debulked flat laminate to the mandrel and secure in place with tape at each end.
- Drape a layer of nylon film and mockburg paper breather over the surface of the flat laminate.
- Drape the vacuum bag over the layup, seal and draw vacuum. Insure that the vacuum bag conforms to the radius areas by rubbing with a teflon paddle. This operation will form the flat debulked laminate with TX1040 in place over the mandrel, wrinkle free. The laminate preform, with integral 45° bias TX1040 separators will remain secured to mandrel.

- Remove nylon bag, mockburg breather, and bias ply of TX1040.

- Place the shaped $(0)_{16}$ cap element prepared per 3.4 over the ($\pm$ 45) 2 ply layup on the tool cap. Tack in-place on each end with a small piece of tape.

- Cut a 15.2 cm (6.0 inch) wide strip from the debulked 2 ply ($\pm$ 45) flat laminate (outer element) to the desired length for the outer layer of the hat-section. Remove the single ply of TX1040. The bias oriented TX1040 and 120 fiberglass bleeder are to remain in place.

- Place the laminate on the $(0)_{16}$ cap element to have the graphite surfaces in contact. Secure each end to mandrel with tape.

- Repeat the above vacuum forming operation. In order to prevent the outer plies from tacking to the flange of the inner plies, insert a strip of polyethelene, or F.E.P. film between the two preforms along each flange. During the vacuum forming operation rub and force the bag into the radius areas with a teflon paddle.

- Remove the vacuum bag and then carefully remove the two parting film strips from between each flange of the "hat".

- Tack the two flanges into final position.

- Drape a parting film such as nylon or F.E.P. over the vacuum formed hat assembly. Install the SMC250 molded silicone rubber caul over the parting film. Seal in a nylon film vacuum bag, place in an autoclave, apply vacuum and pressurize to 689 KN/m^2 (100 psi). Hold under pressure for approximately 15 minutes. This operation is performed to insure proper seating of prepreg preforms, bleeder materials and rubber caul.

- Remove bag, rubber tooling and parting film and inspect for part conformance to the tooling.

- Apply Frekote 33 parting agent to the rubber caul. Air dry for 15 minutes minimum.

- Install the rubber caul over the ($\pm$ 45) 120 fiberglass bleeder surface of the preformed hat.

- Place the mandrel on a flat steel tool suitable for curing parts at 1378 KN/m^2 (200°psi), 287 C (550°F). Install shims under the curved base of the tool to prevent bending the tool when autoclave pressure is applied.

- Install 162 fiberglass breather material over the external surfaces of the rubber caul. Apply material as required to prevent bridging and any sharp protrusions from coming in contact with the bag. Adequate breather material shall be placed between the part and vacuum source to insure efficient removal of volatiles.

- Install thermocouples into the edge of the part under the rubber caul in areas designated by engineering personnel. These thermocouples shall be used in monitoring and recording time/temperature data during cure and shall be used to control the cure cycle.

- Install a 0.051 mm (0.002 inch) thick Kapton film bag over the breather and tool surfaces and seal around the periphery of the tool using G.S. 43 sealant or equivalent. Insure that no bridges exist or sharp protrusions bear against the vacuum bag. Make vacuum bag "ear" seals as required to insure adequate bag slack to prevent bridging.

- Install the steel clamping ring and secure with bolts around the periphery of the tool. The tooling arrangement is shown in Figure A8.

3.6 AUTOCLAVE CURE PROCEDURE

- Install the tooling in an autoclave and apply full vacuum. Apply 100 psi to the autoclave and inspect the system for leaks. If a vacuum leak greater than 33.7 KN/m^2 (10 inches Hg) occurs within 5 minutes, the source shall be located and repaired.

- Perform the in situ imidizing and cure cycle within the time temperature profile of Figure A9. Record all events such as application of various levels of vacuum, pressure and autographically record temperature from each thermocouple on parts and autoclave. The part thermocouples shall be used in controlling the cure cycle. All part temperatures shall be in the range of 274 to 287°C (525°F to 550°F) when 1378 KN/m^2 (200 psi) autoclave pressure is applied. The ultimate cure temperature shall not exceed 293°C (560°F).

- Force cool the part to < 65°C (< 150°F) prior to pressure release.

- Remove the part from the tooling. Care shall be exercised to prevent tearing the rubber caul during removal from the surface of the bleeder material on the part.

- Remove bleeder materials and clean up parts.

- Submit to Quality Engineering for NDI C-scan test.

3.7 POSTCURE PROCEDURE

- Postcure the hat-section in an air circulating oven by raising the oven and part temperature from room temperature to 316°C (600°F) at an average heat rise rate of 1.6 to 8.3°C (3 to 15°F)/minute and hold at temperature for 4 hours. The hat-section shall be supported on a flat base, free standing, during postcure.

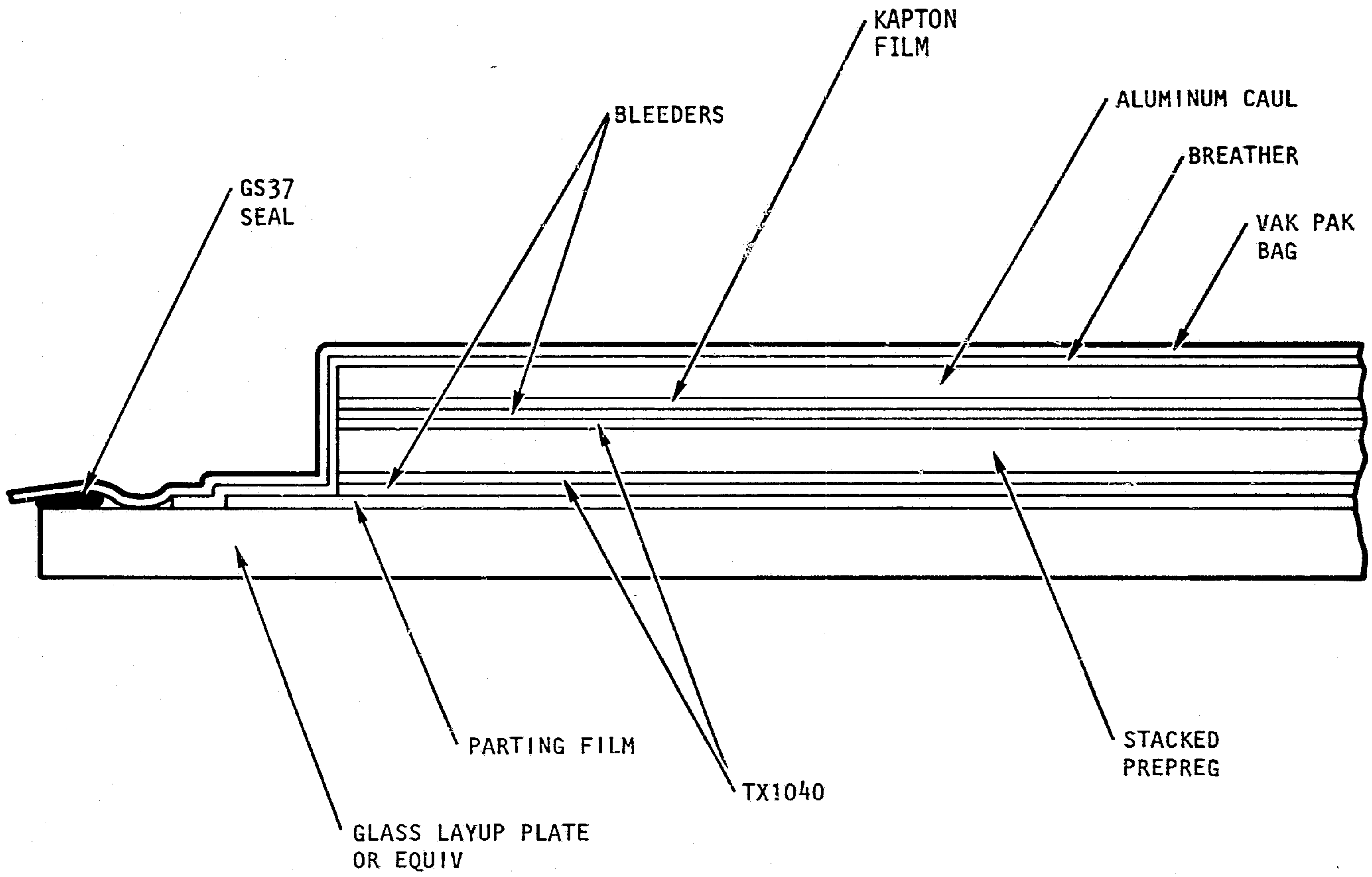

Figure A1. Crossection LARC-160/Celion Prepreg Layup and Debulking Details

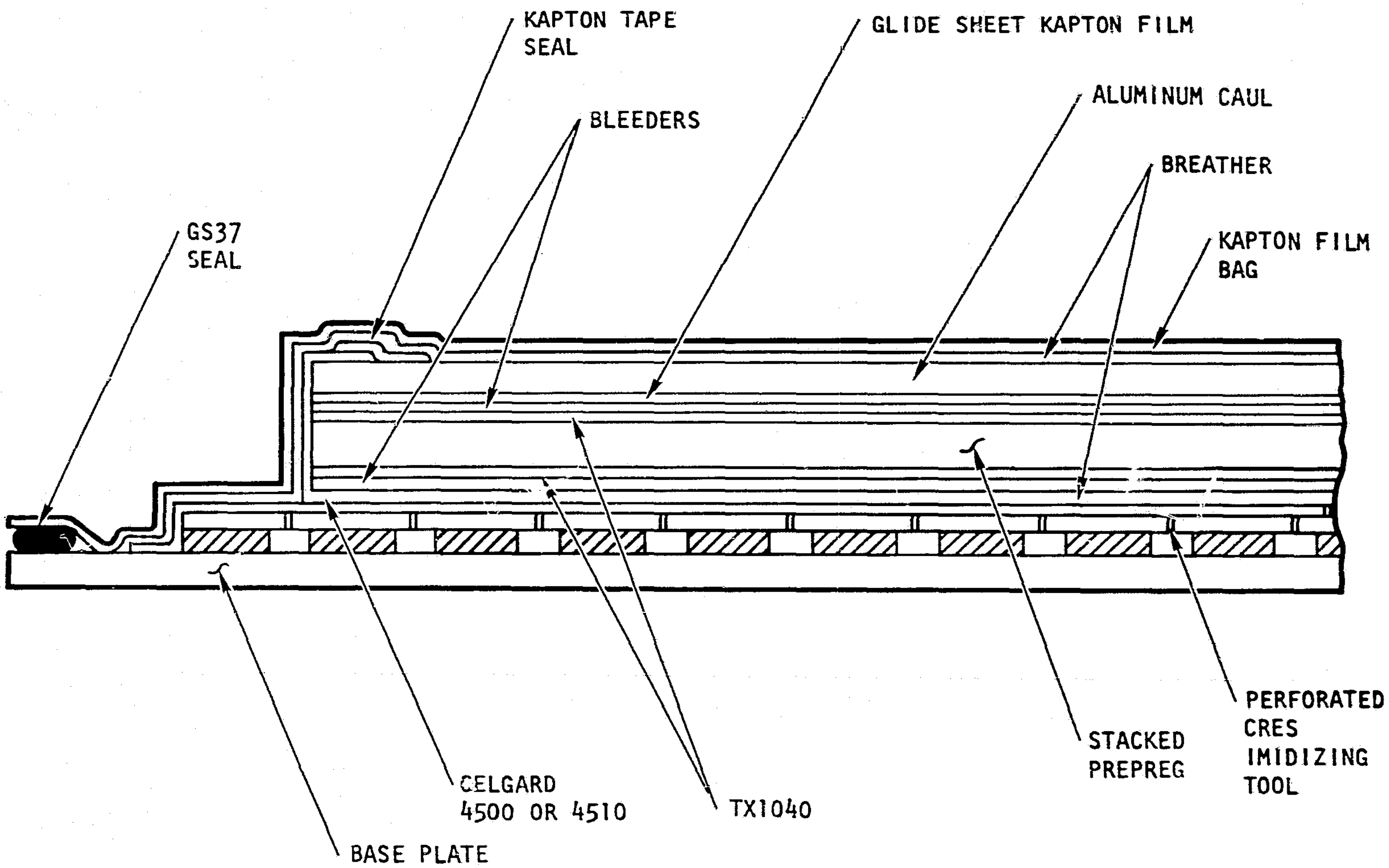

Figure A2. Crossection LARC-160/Celion Prepreg Layup Imidizing Details

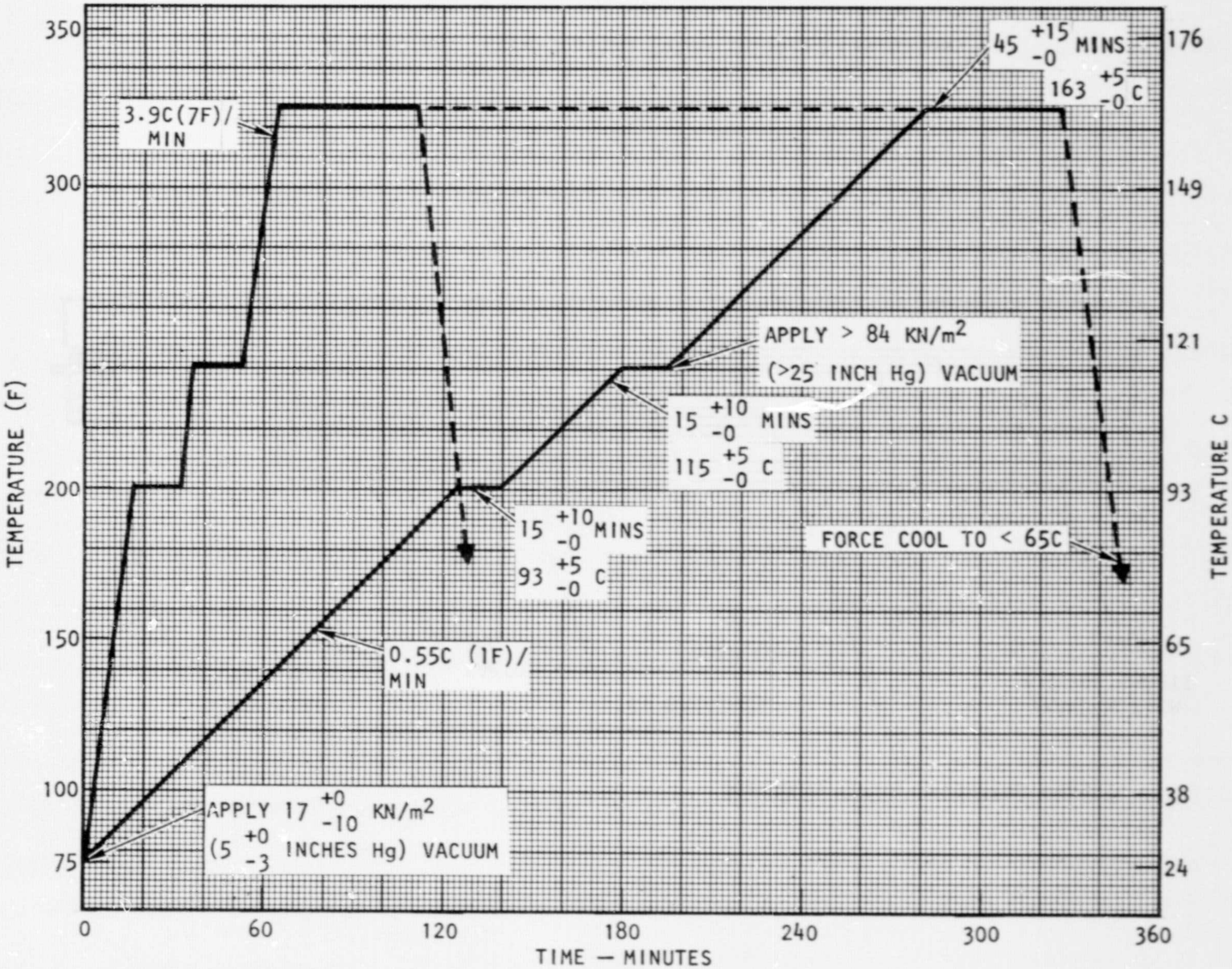

Figure A3. LARC-160/Celion Imidizing Cycle and Sequence of Events

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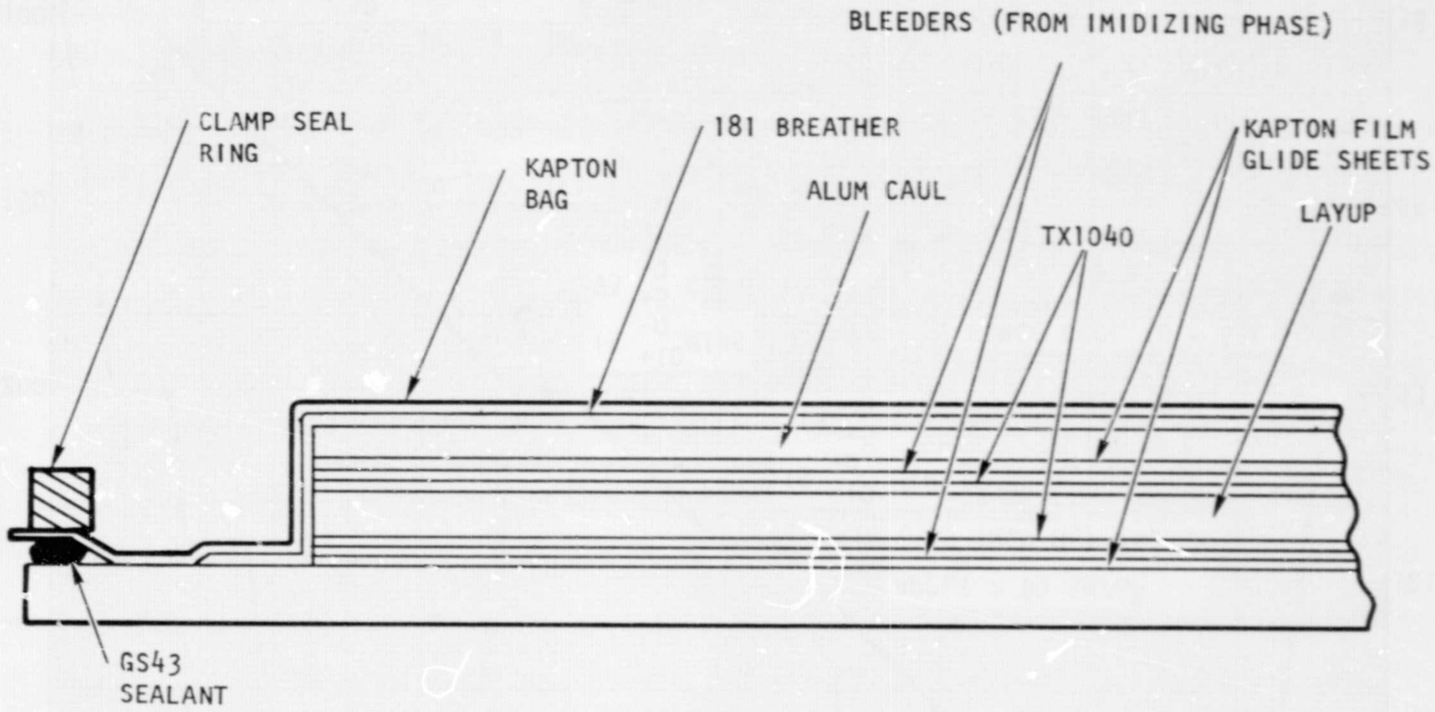

Figure A4. Cure Tooling Setup Imidized Laminates

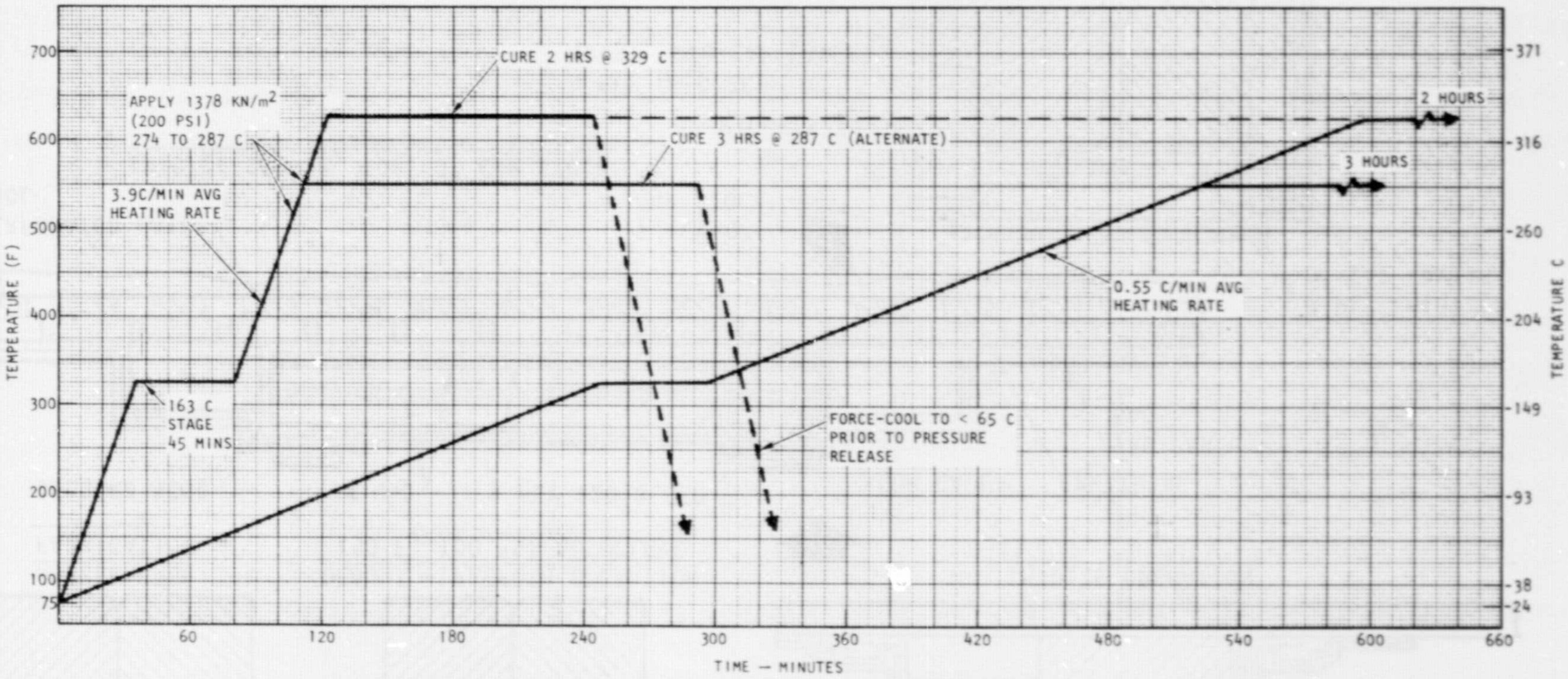

Figure A5. LARC-160/Celion Cure Cycle and Sequence of Events (Imidized Prepreg)

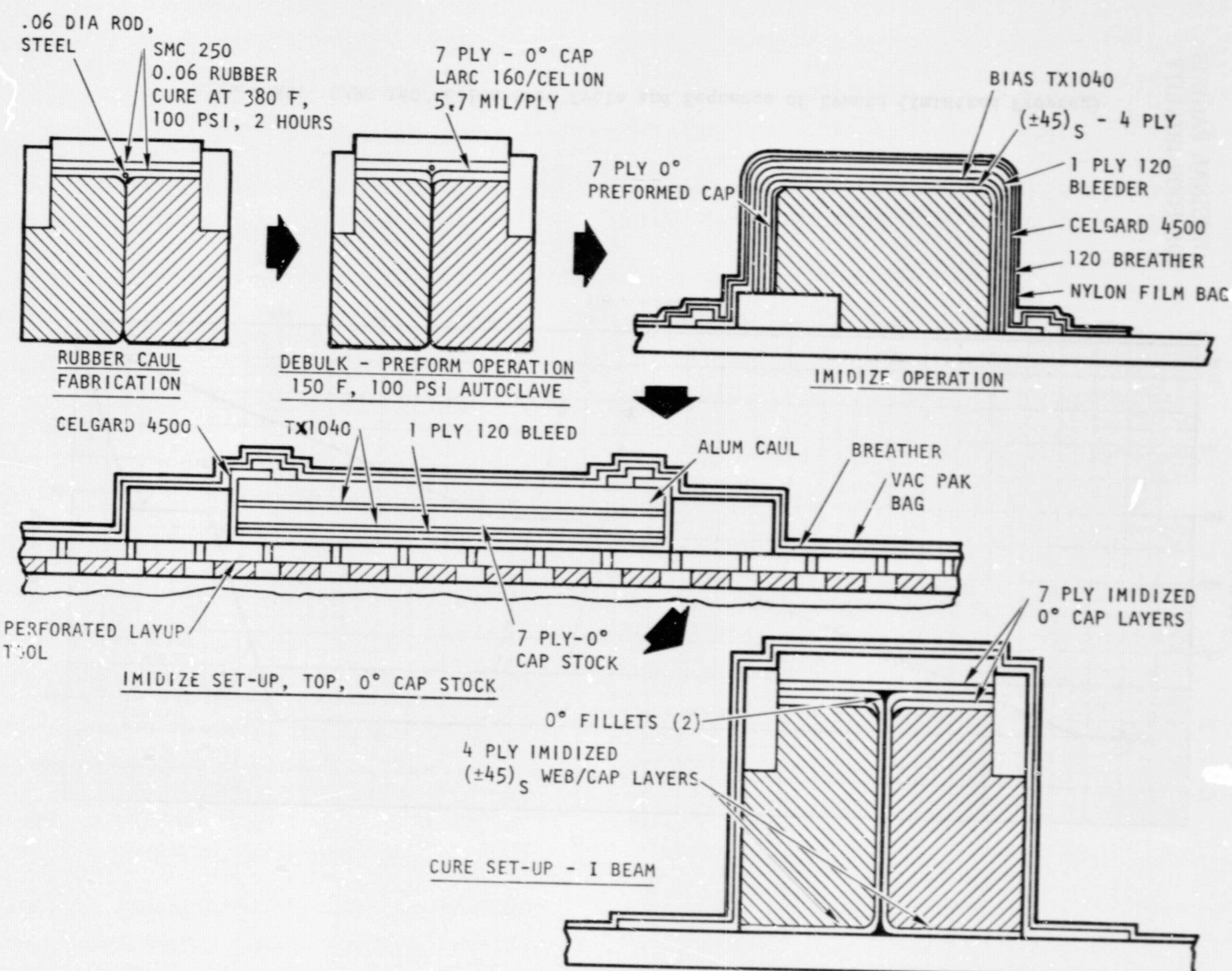

Figure A6. Layup Sequence LARC-160/Celion "I" Beam - Balanced Cap

MOLDING PRESSURE CRITERIA (1)(2)(3)

VACUUM PRESSURE LEVEL		PRESSURE TO AUGMENTER PLATE		AUGMENTED PRESSURE TO FILLET	
KN/m^2	INCHES HG	KN/m^2	PSI	KN/m^2	PSI
6.75	2	6.75	0.98	48	6.9
84.0	25	84.0	12.2	586	85
101	30	101	14.7	710	103

(1) PRESSURE AUGMENTER PLATE AREA RATIO TO MANDRELS = 7:1

(2) PROCESS PER 1.1 AND 1.2.

(3) Fillet mold is 96.5 CM (38.0 INCHES) LONG

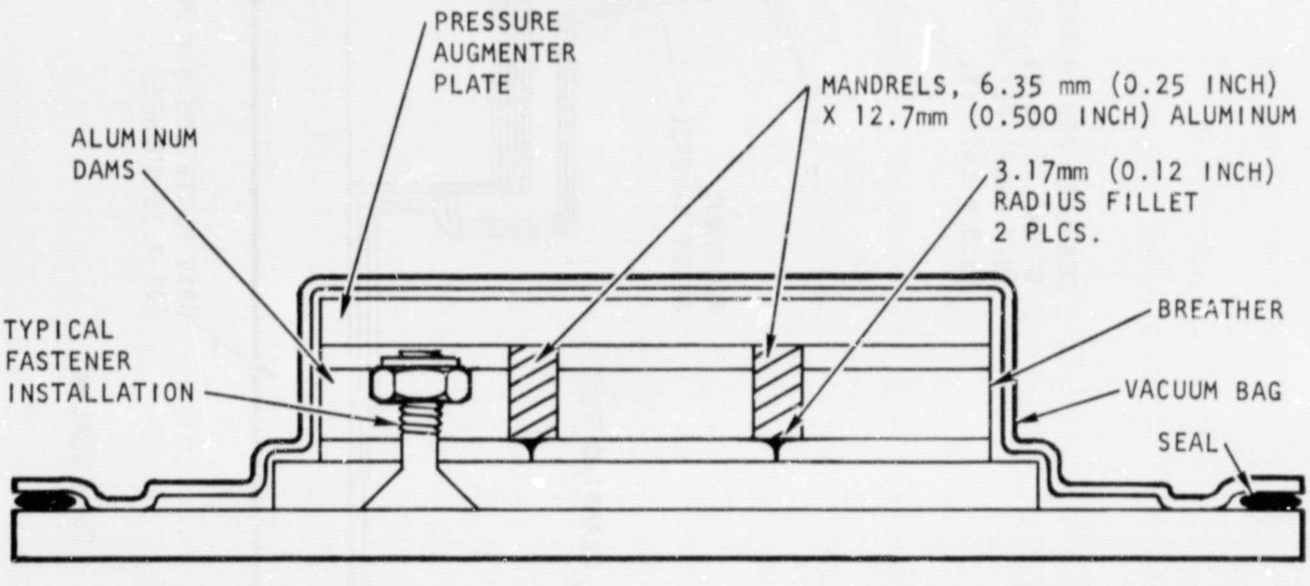

Figure A7. Fillet Radius Stock Tooling and Vacuum Bagging Arrangement - Imidizing Process

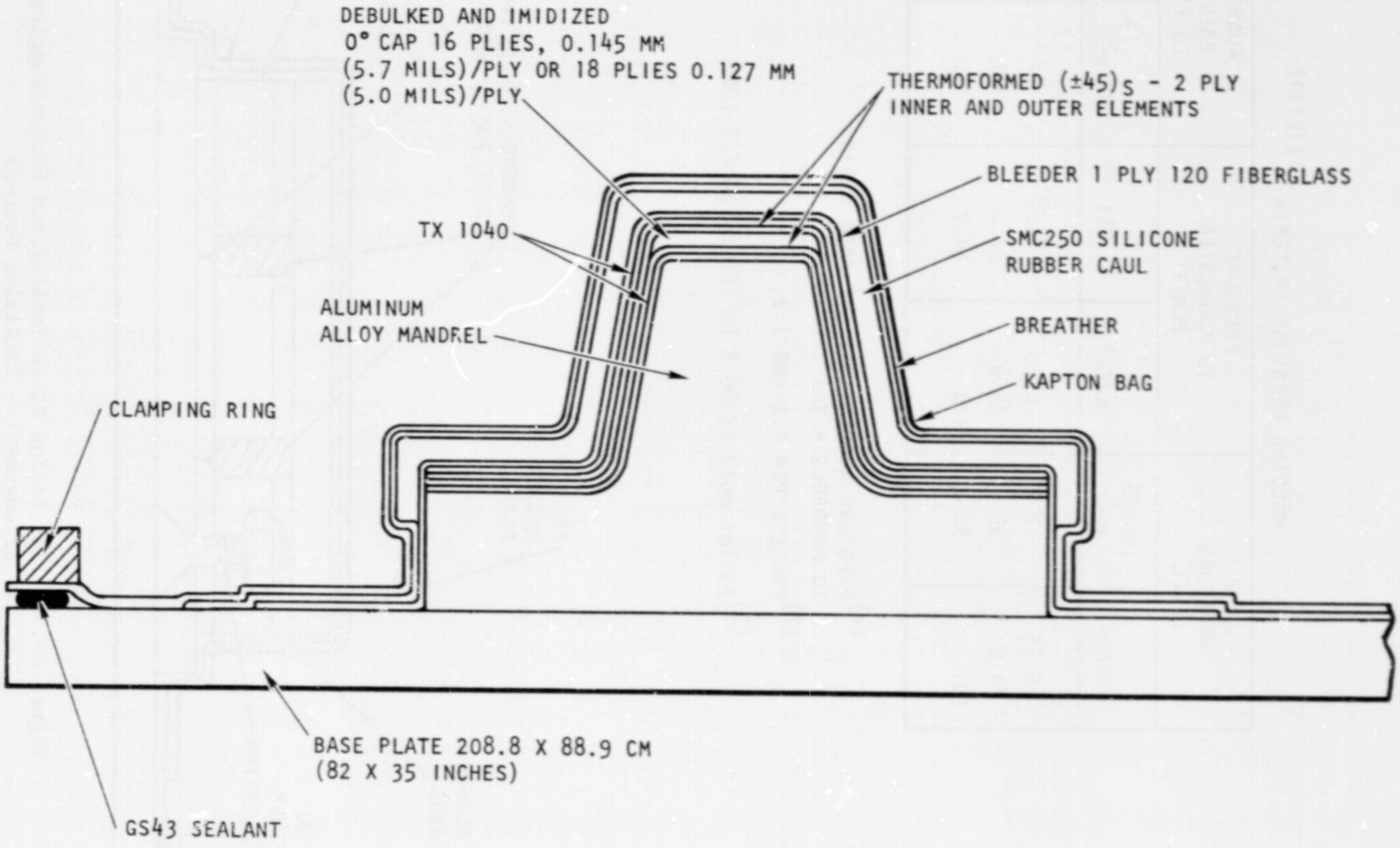

Figure A8. Layup and Tooling Process Hat-Stringer Assembly

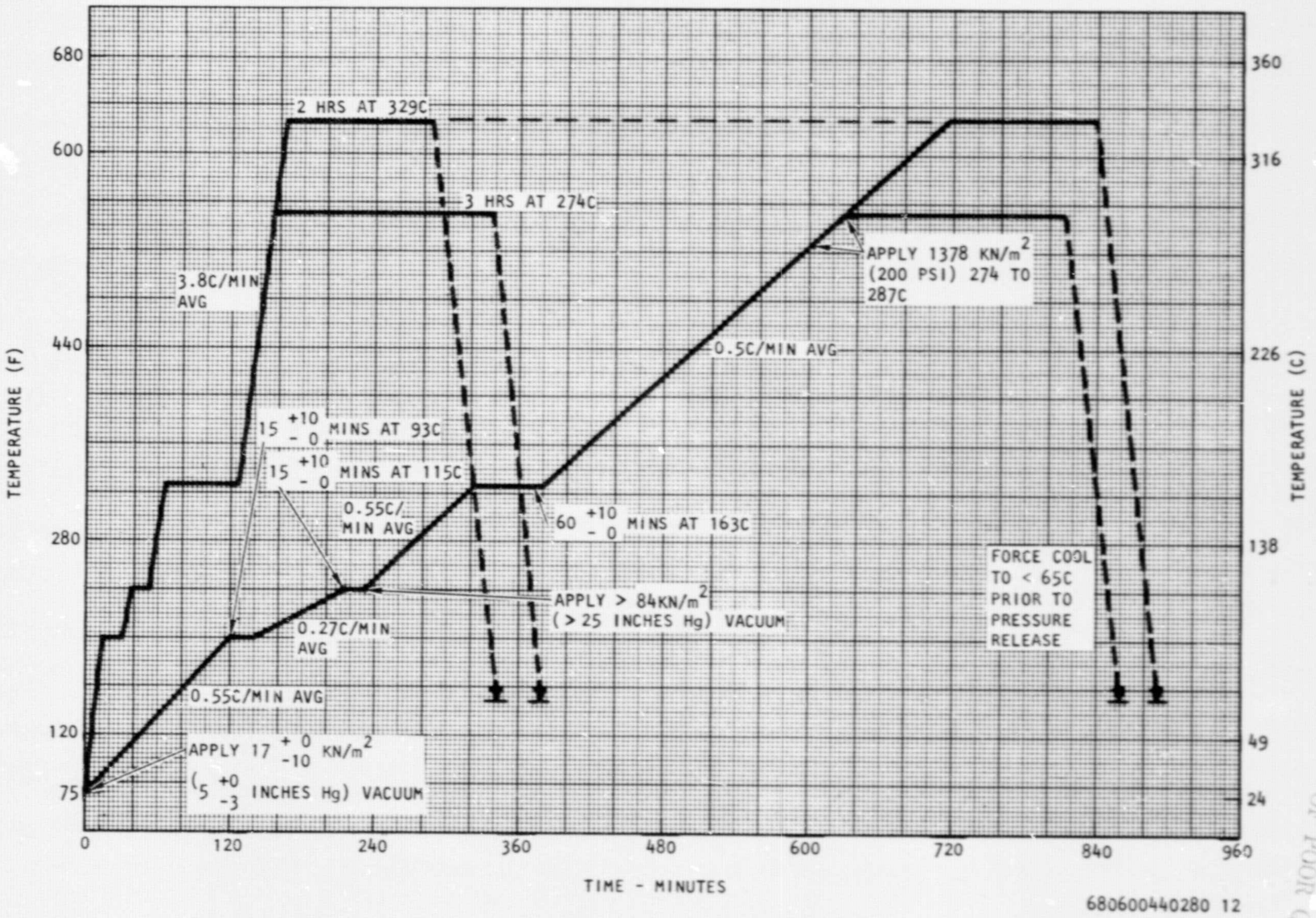

Figure A-9. LARC-160/Celion In Situ Imidizing Cure Cycle and Sequence of Events

APPENDIX B
MECHANICAL PROPERTIES
STRESS/STRAIN CURVES

TENSILE COUPON CURVES

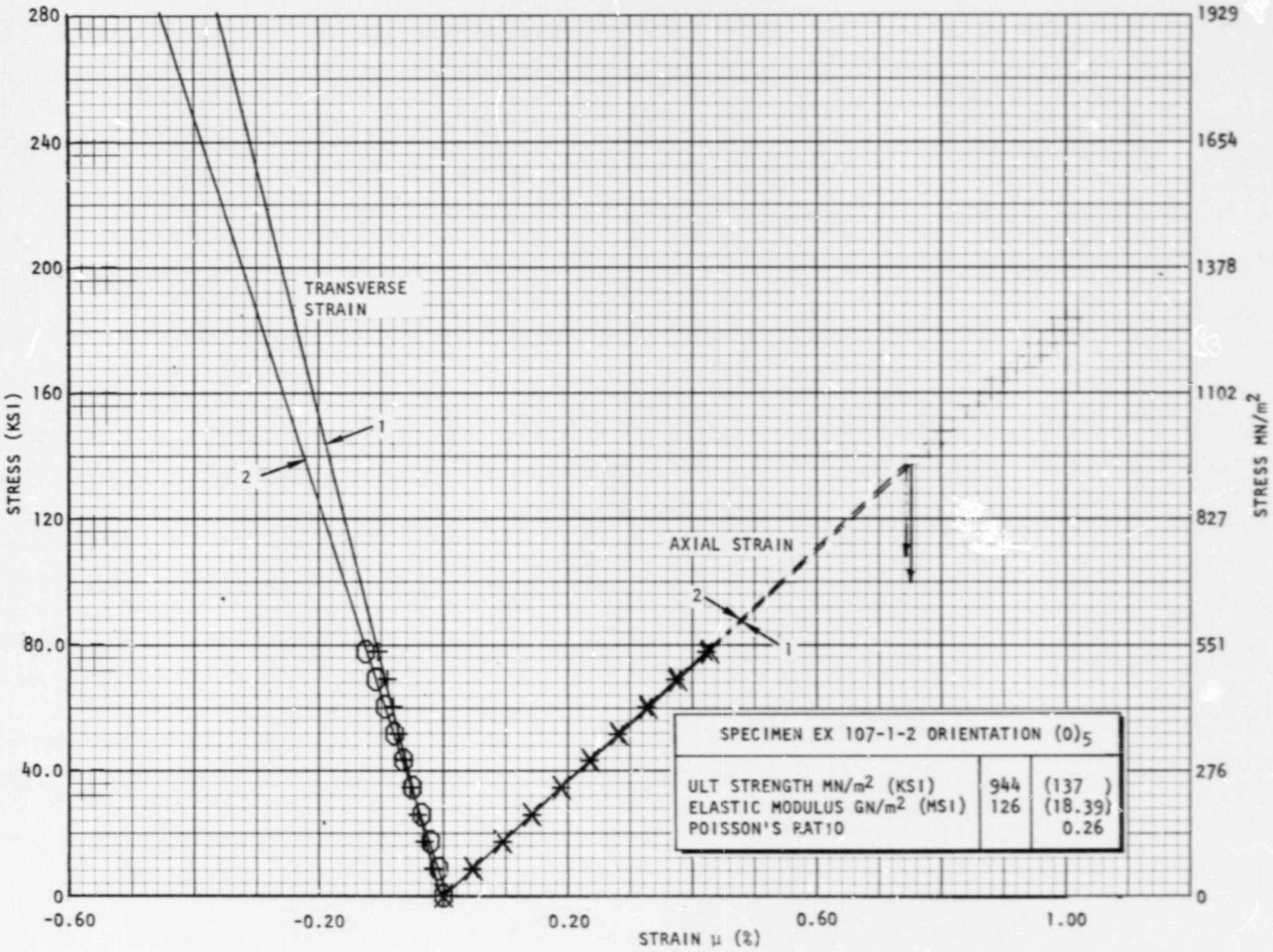

Figure B1. LARC-160/Celion $(0)_5$ Stress/Strain Curves at RT

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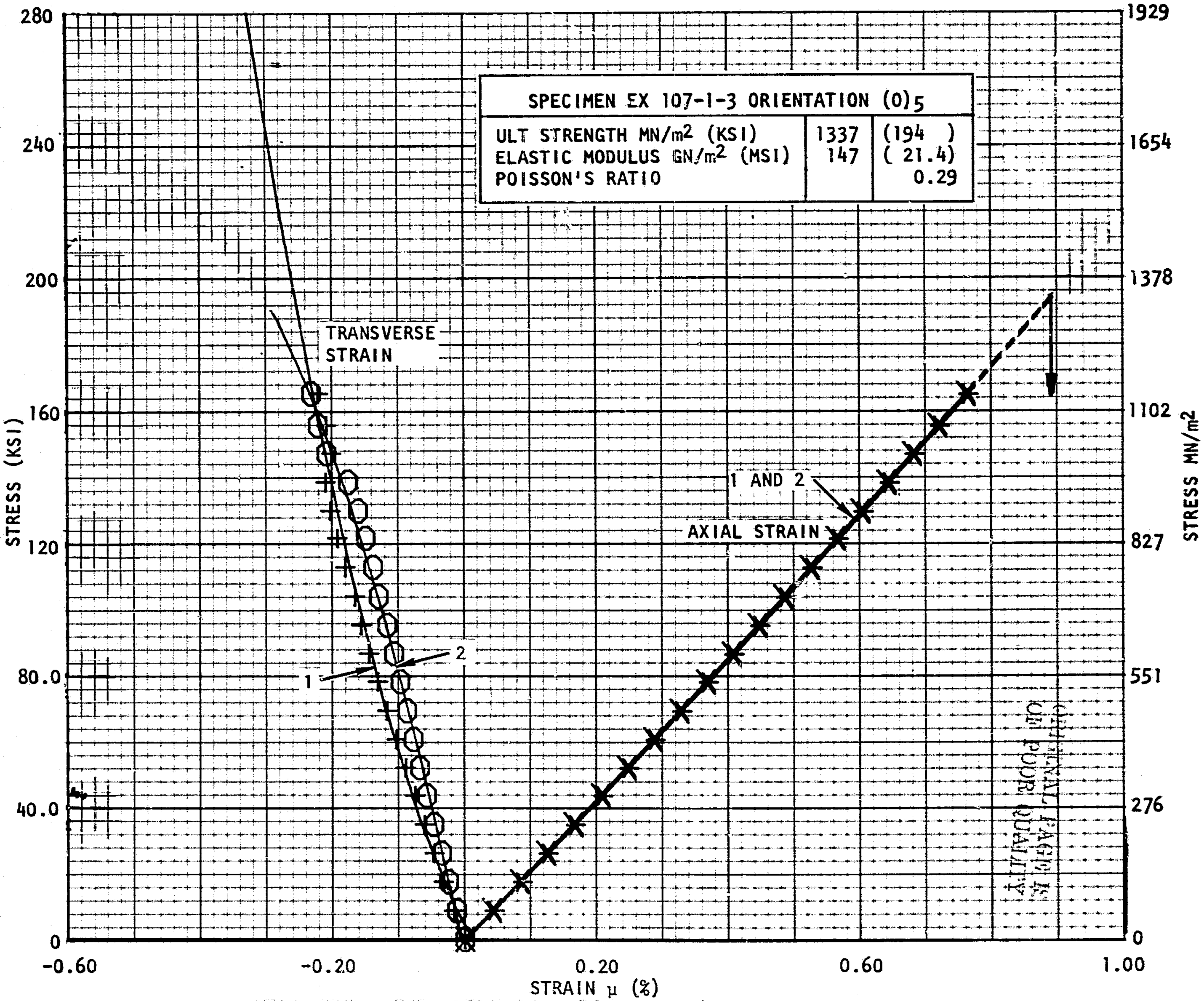

Figure B2. LARC-160/Celion (0)5 Stress/Strain Curves at RT.

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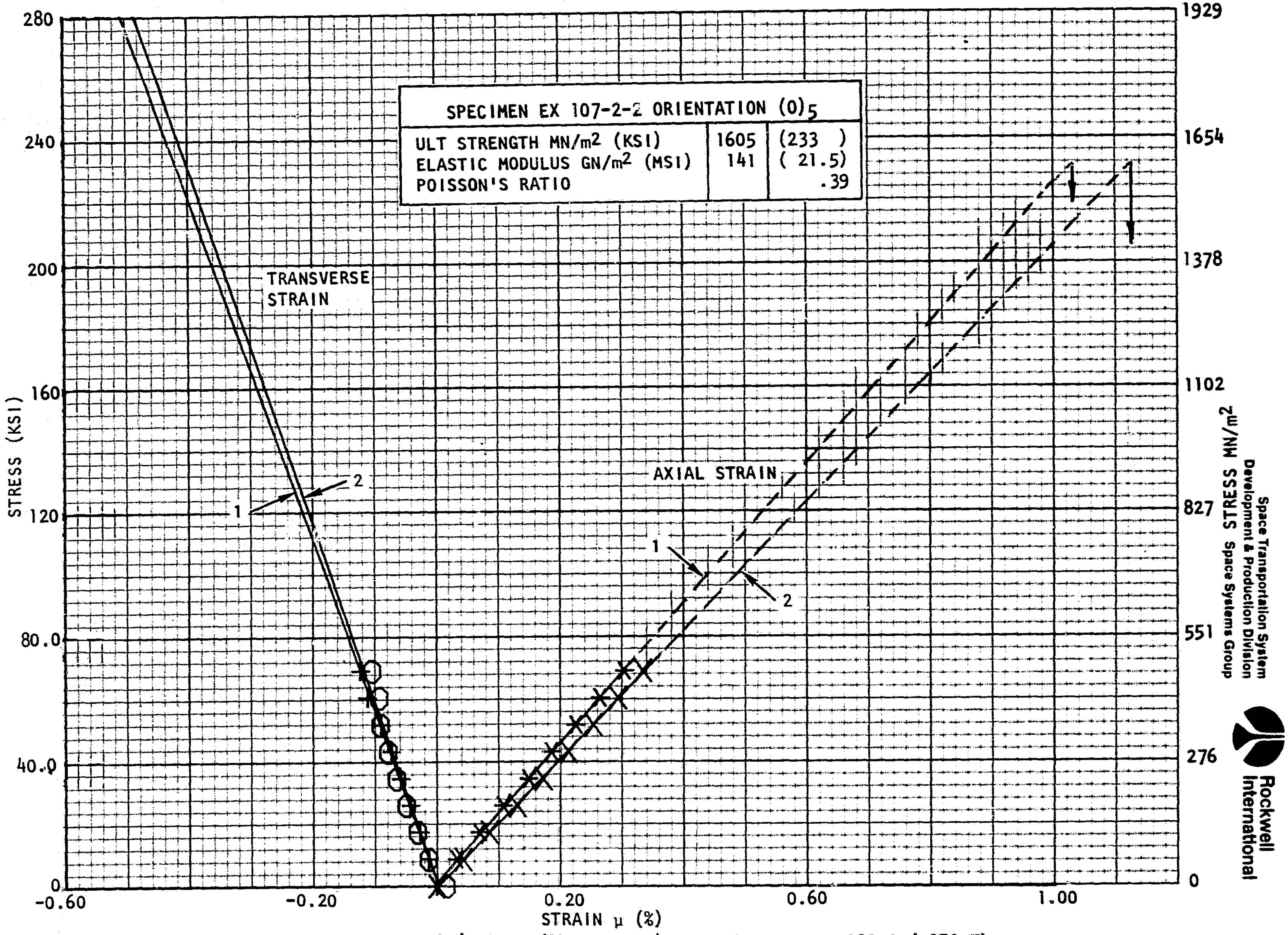

Figure B3. LARC-160/Celion $(0)_5$ Stress/Strain Curves at -132 C (-270 F)

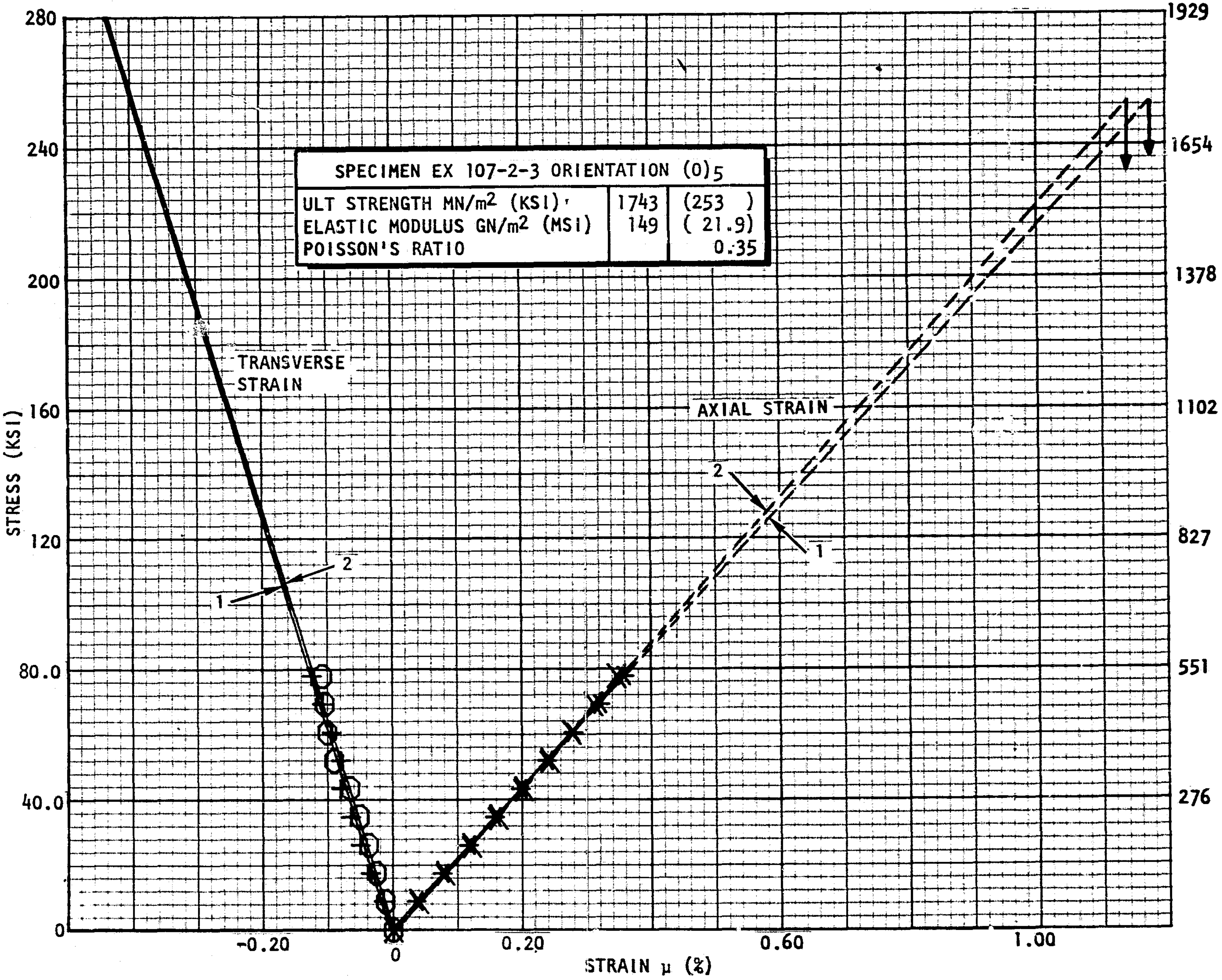

Figure B4. LARC-160/Celion (0)5 Stress/Strain Curves at -132 C (-270 F)

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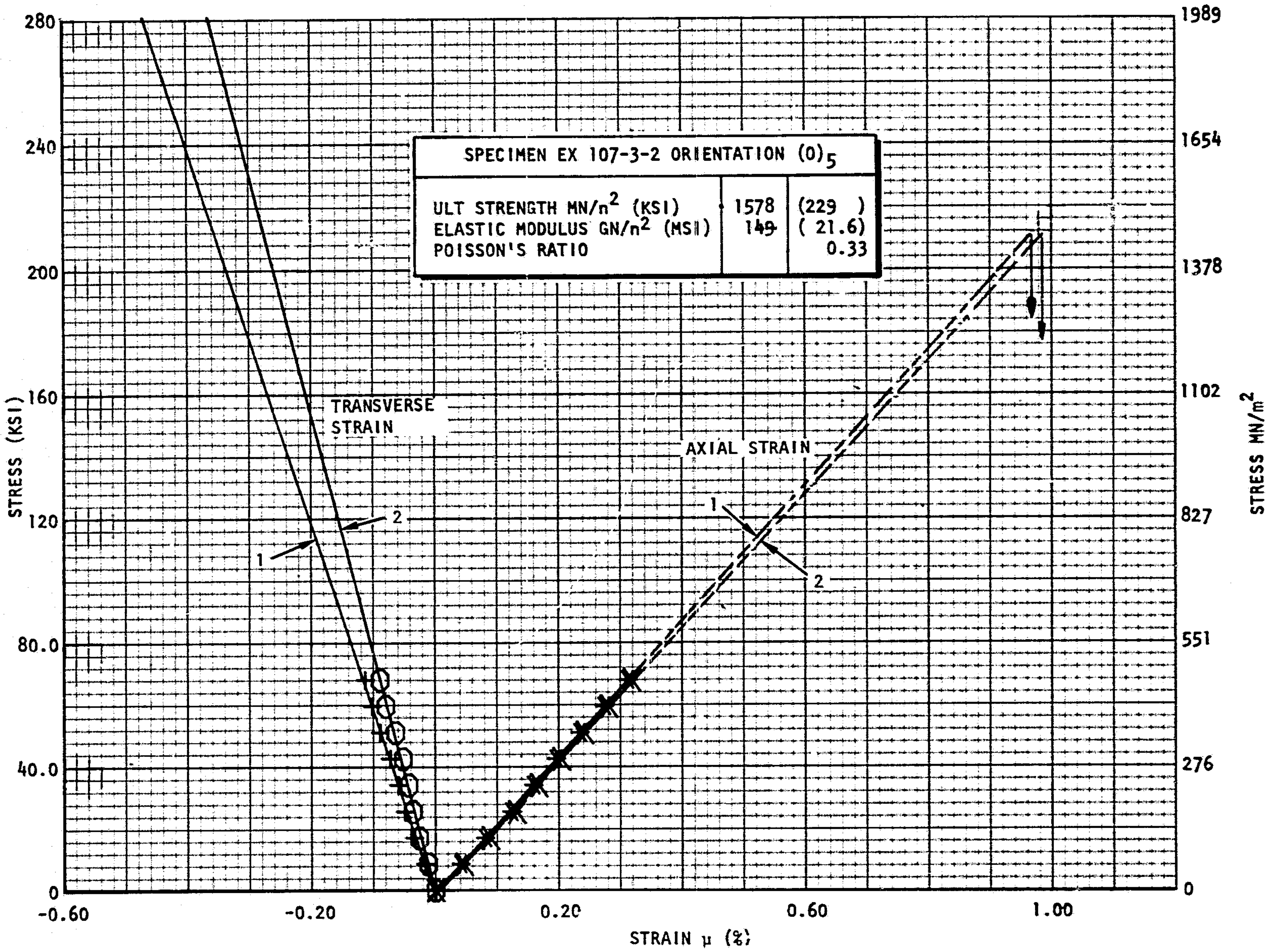

Figure B5. LARC-160/Celion (0)5 Stress/Strain Curves at 204 C (400 F)

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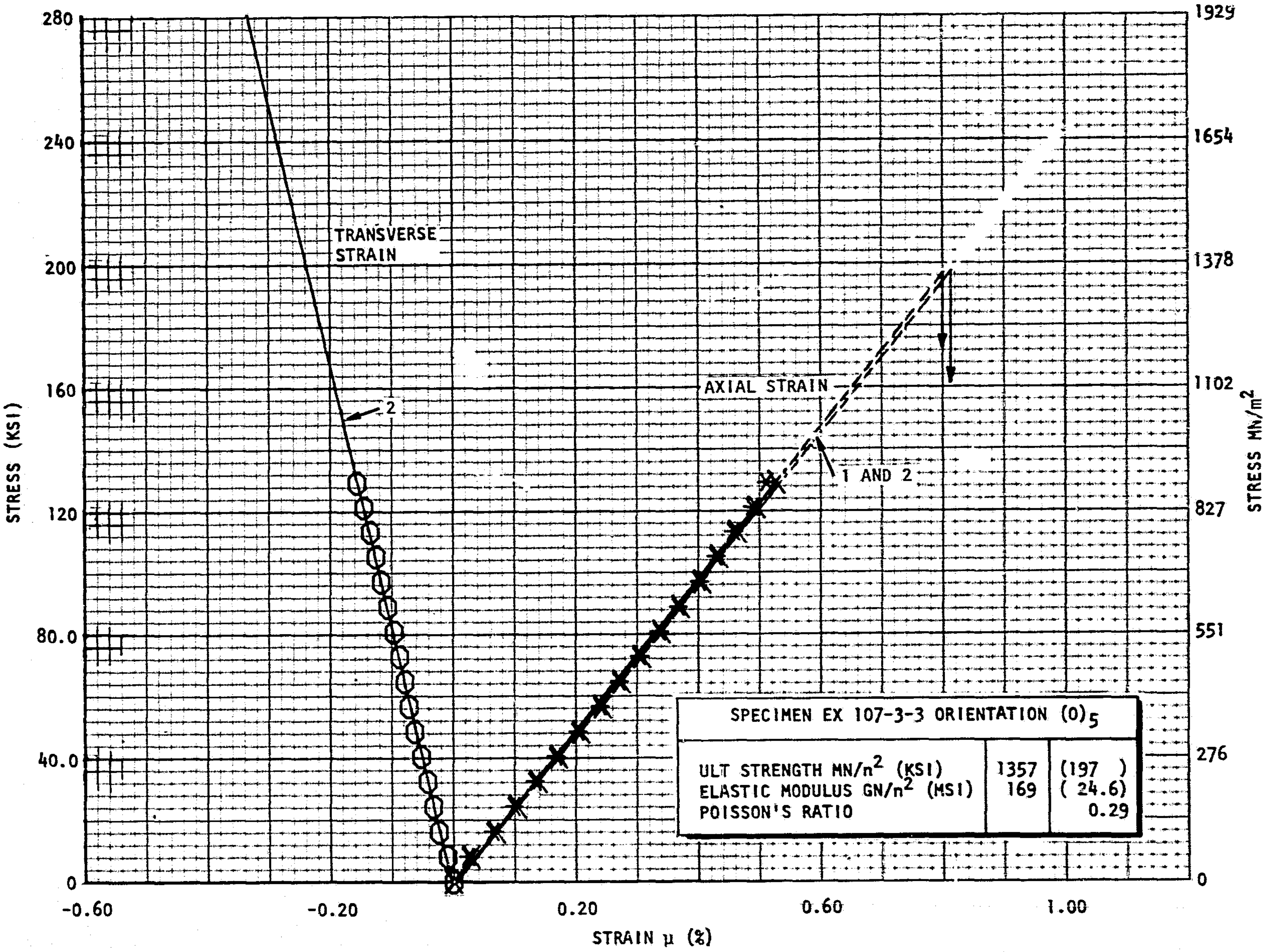

Figure B6. LARC-160/Celion $(0)_5$ Stress/Strain Curves at 204 C (400 F)

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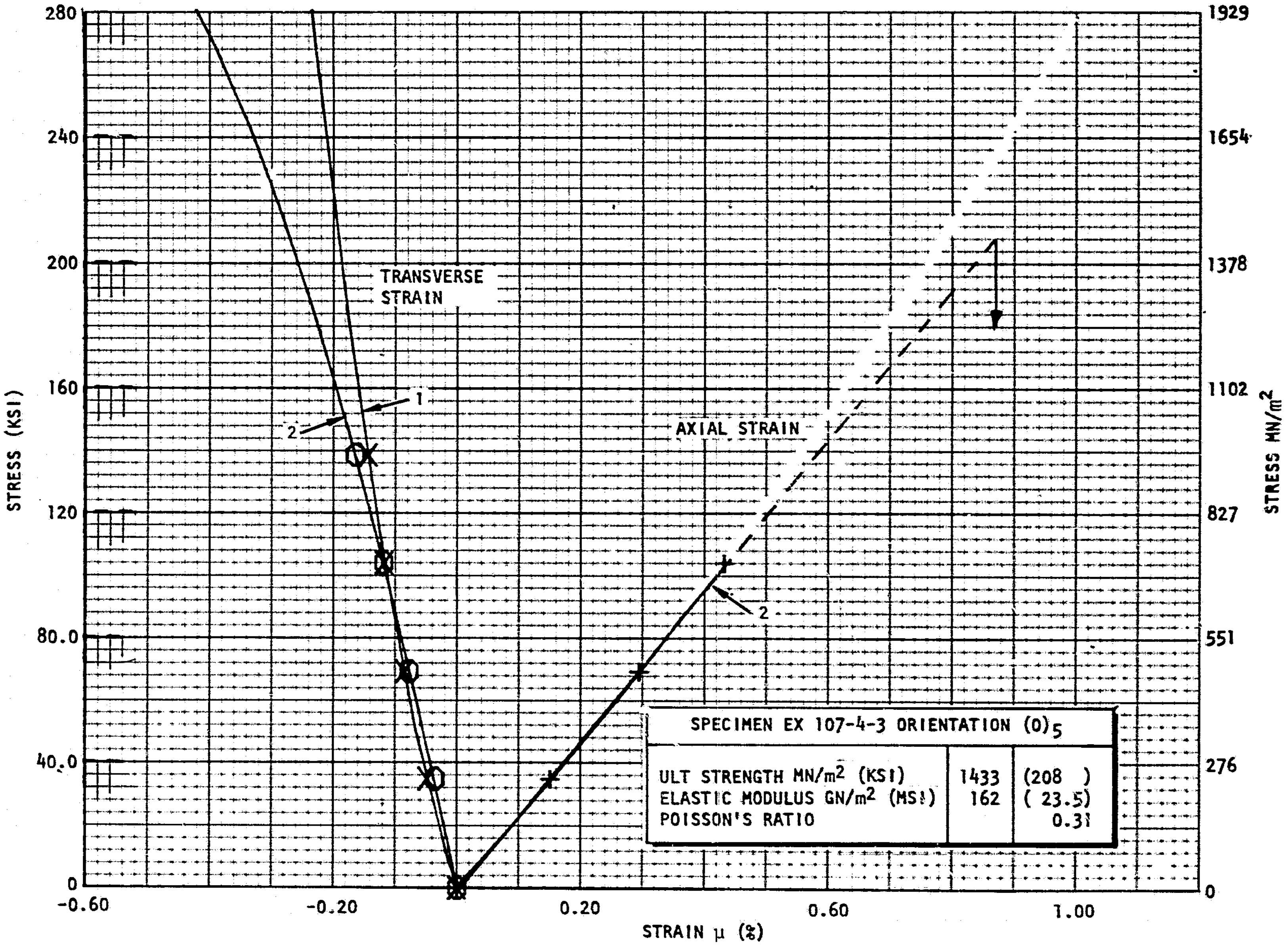

Figure B7. LARC-160/Celion $(0)_5$ Stress/Strain Curves at 316 C (600 F)

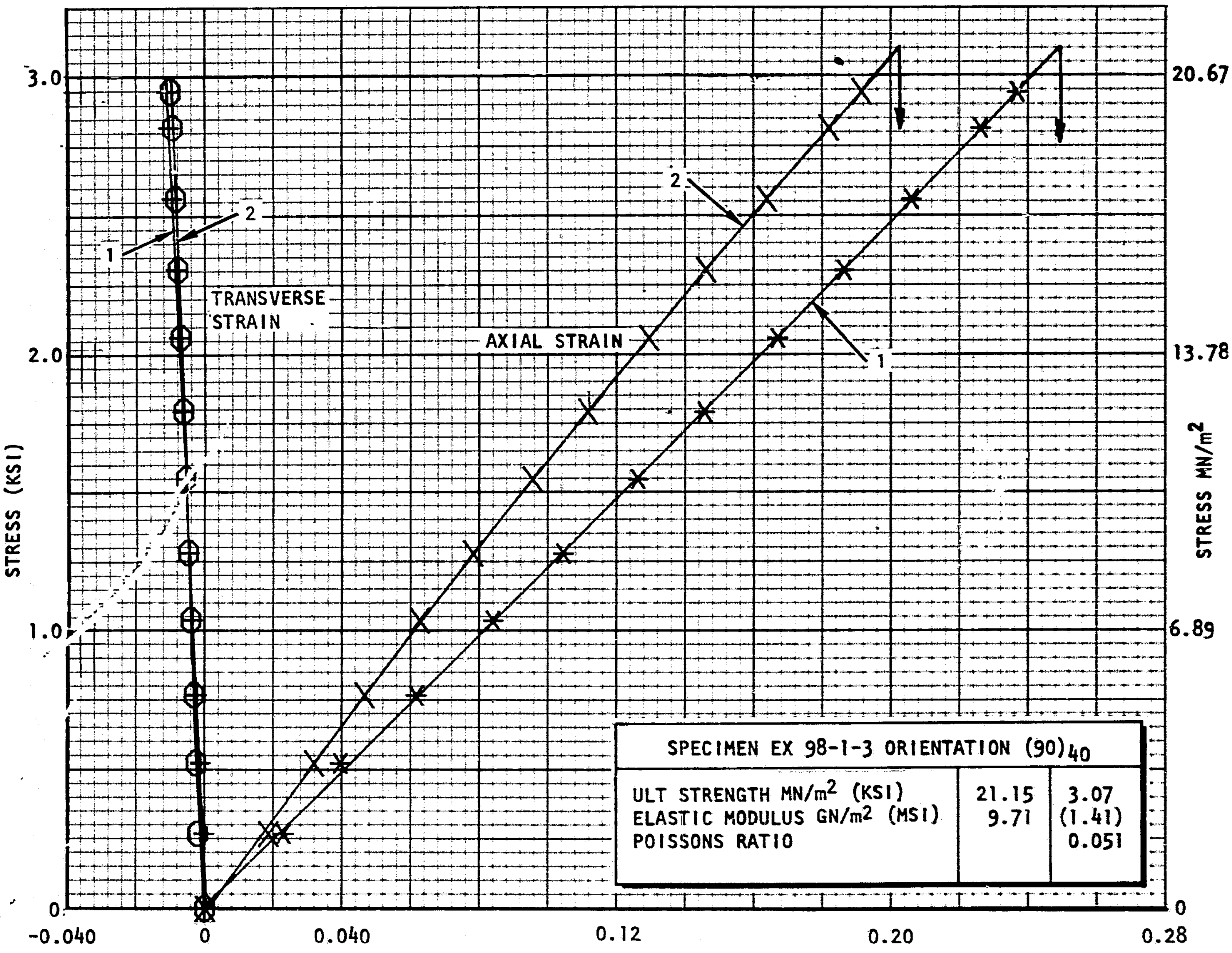

Figure B8. LARC-160/Celion 90° Stress/Strain Curves at RT

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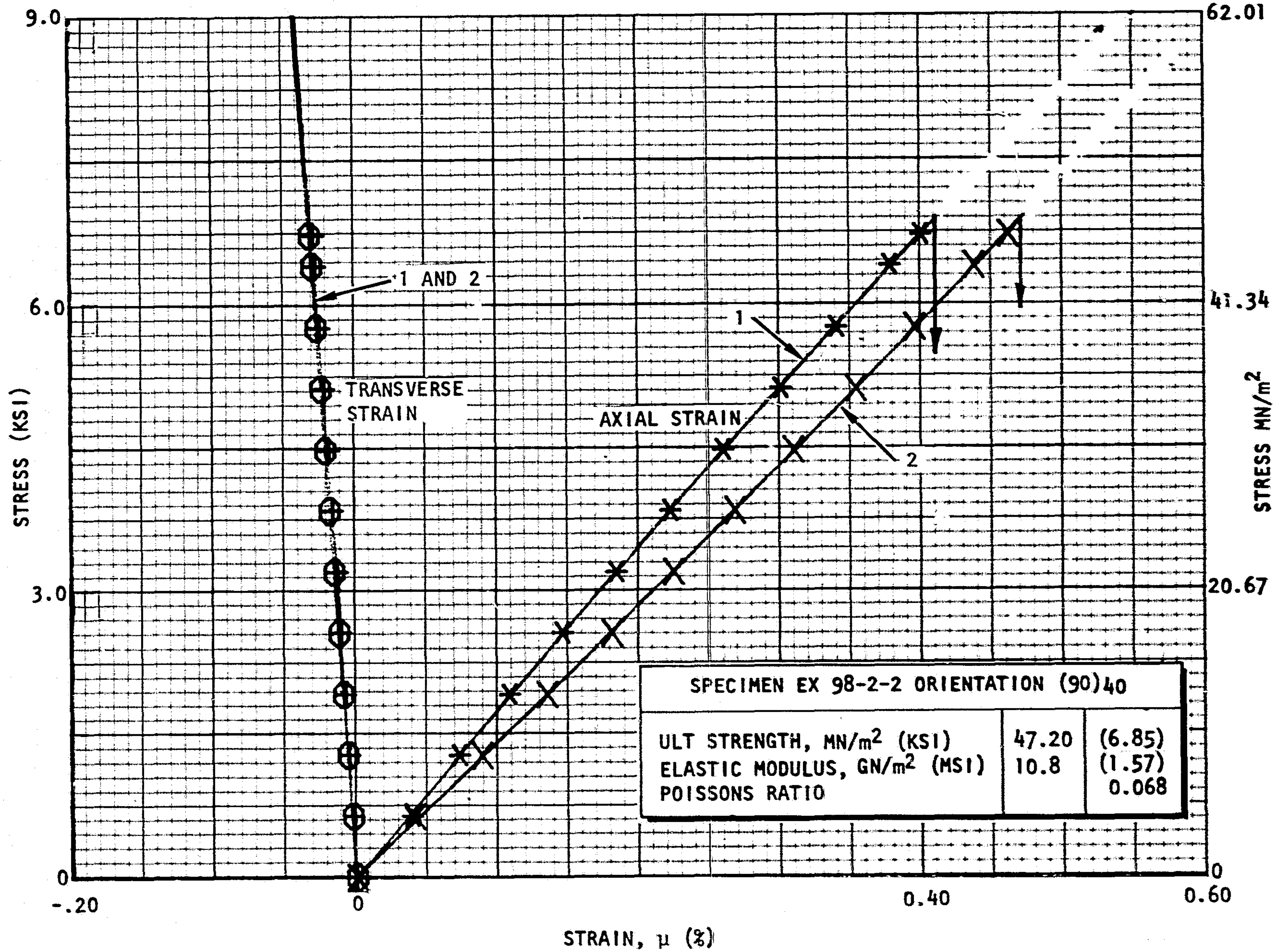

Figure B9. LARC-160/Celion 90° Stress/Strain Curves at -132 C (-270 F)

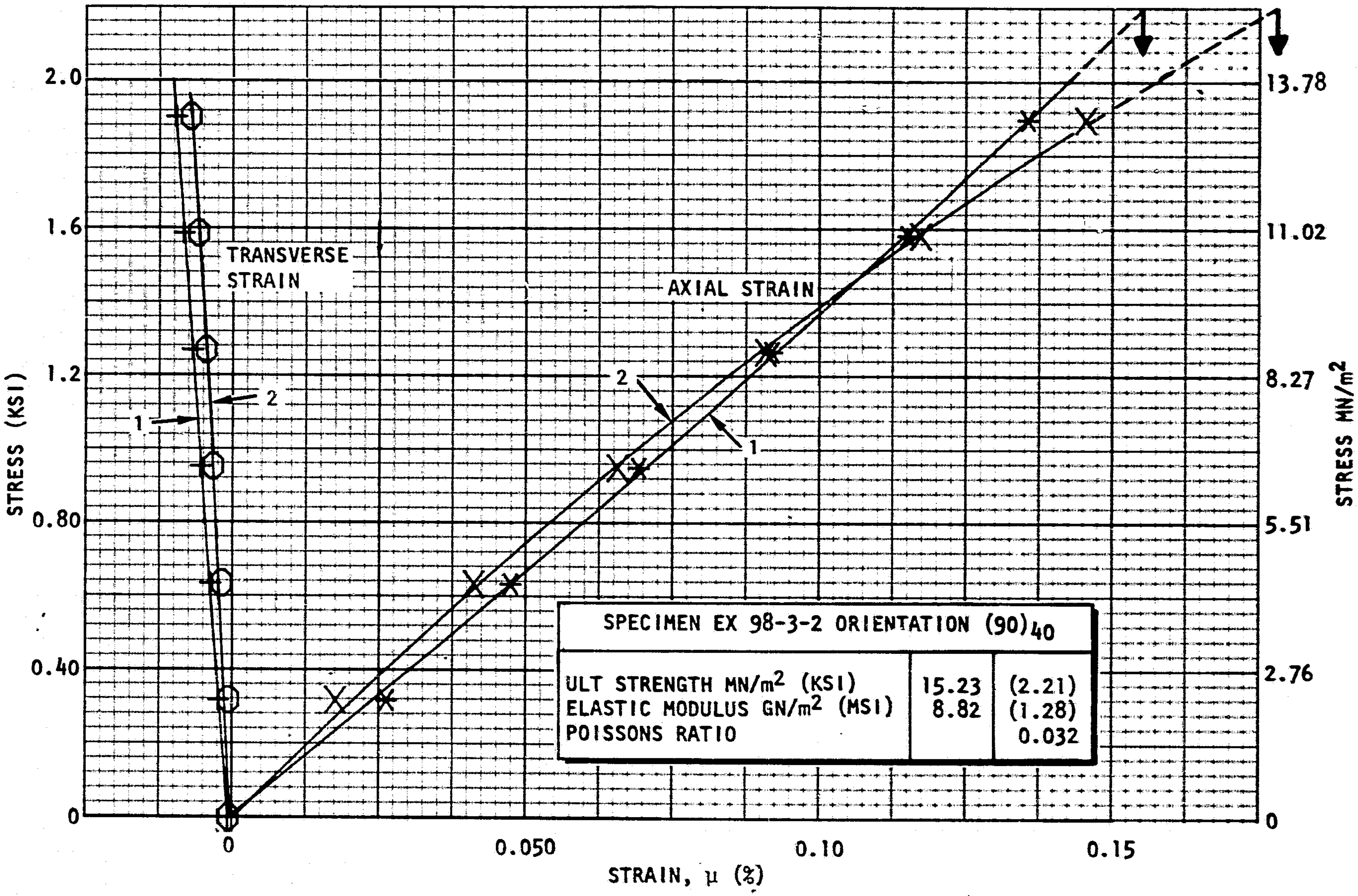

Figure B10. LARC-160/Celion 90° Stress/Strain Curves at 204 C (400 F)

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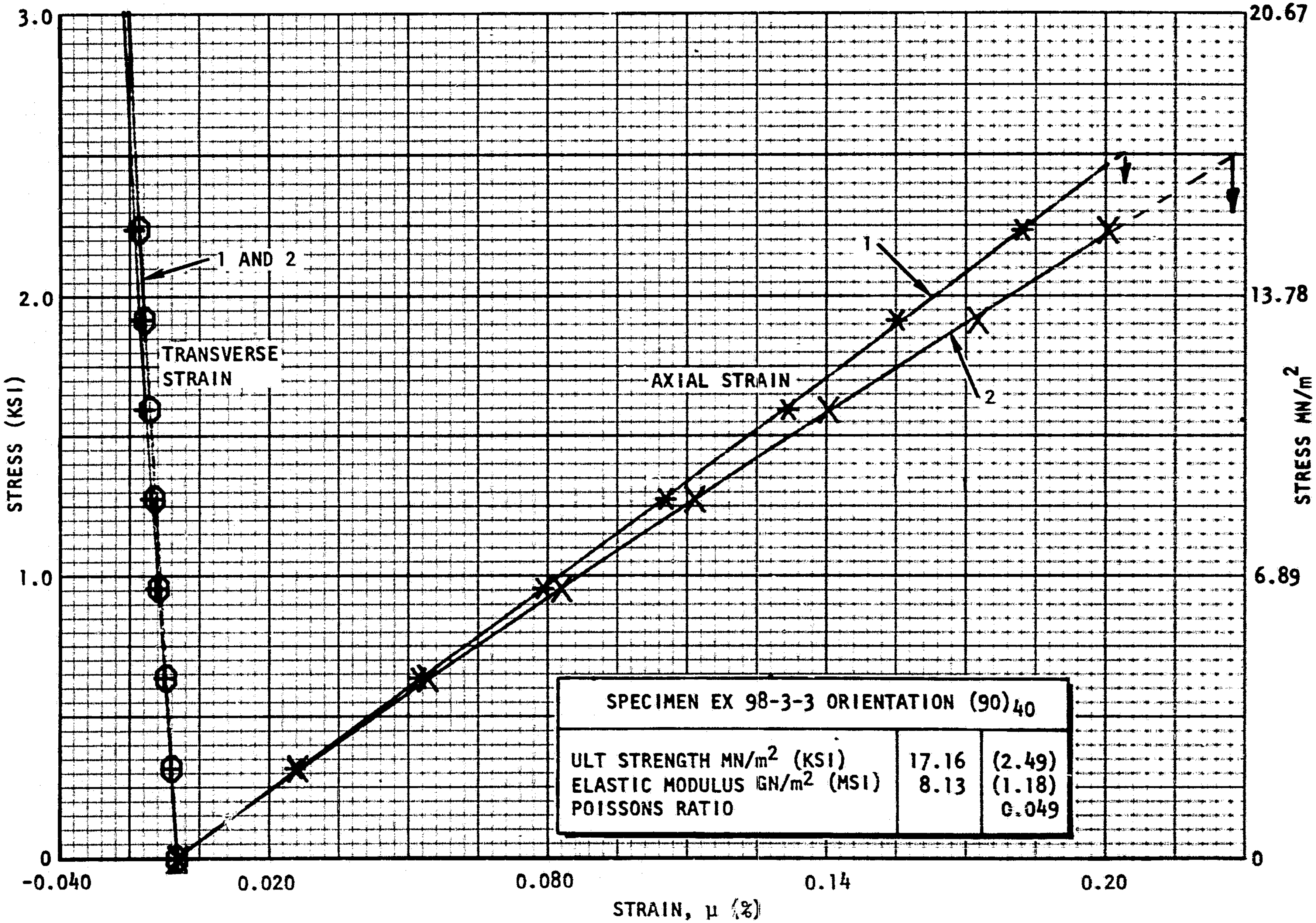

Figure B11. LARC-160/Celion 90° Biaxial Stress/Strain Curves at 204C (400 F)

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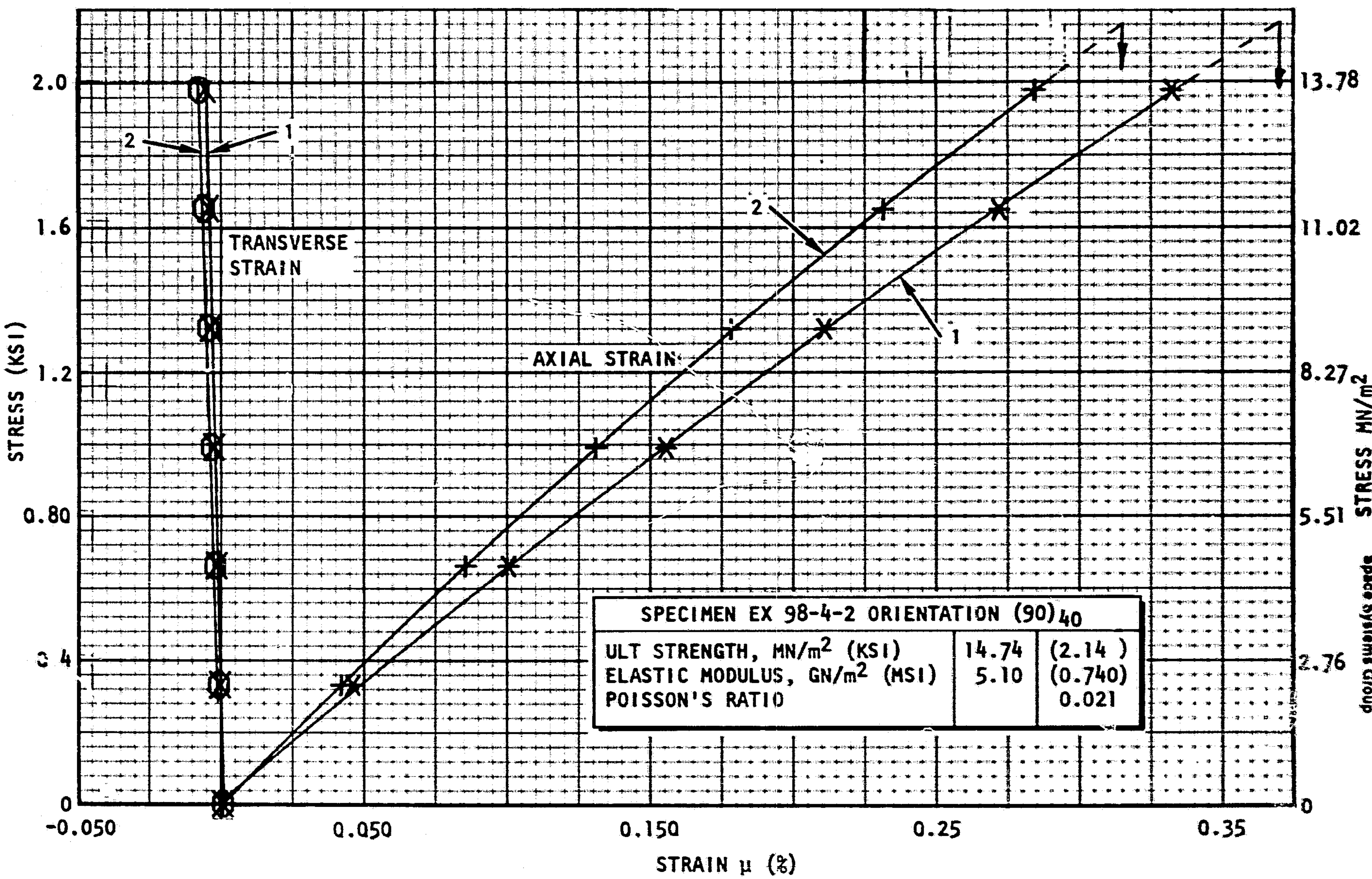

Figure B12. LARC-160/Celion 90° Stress/Strain Curves at 316 C (600 F)

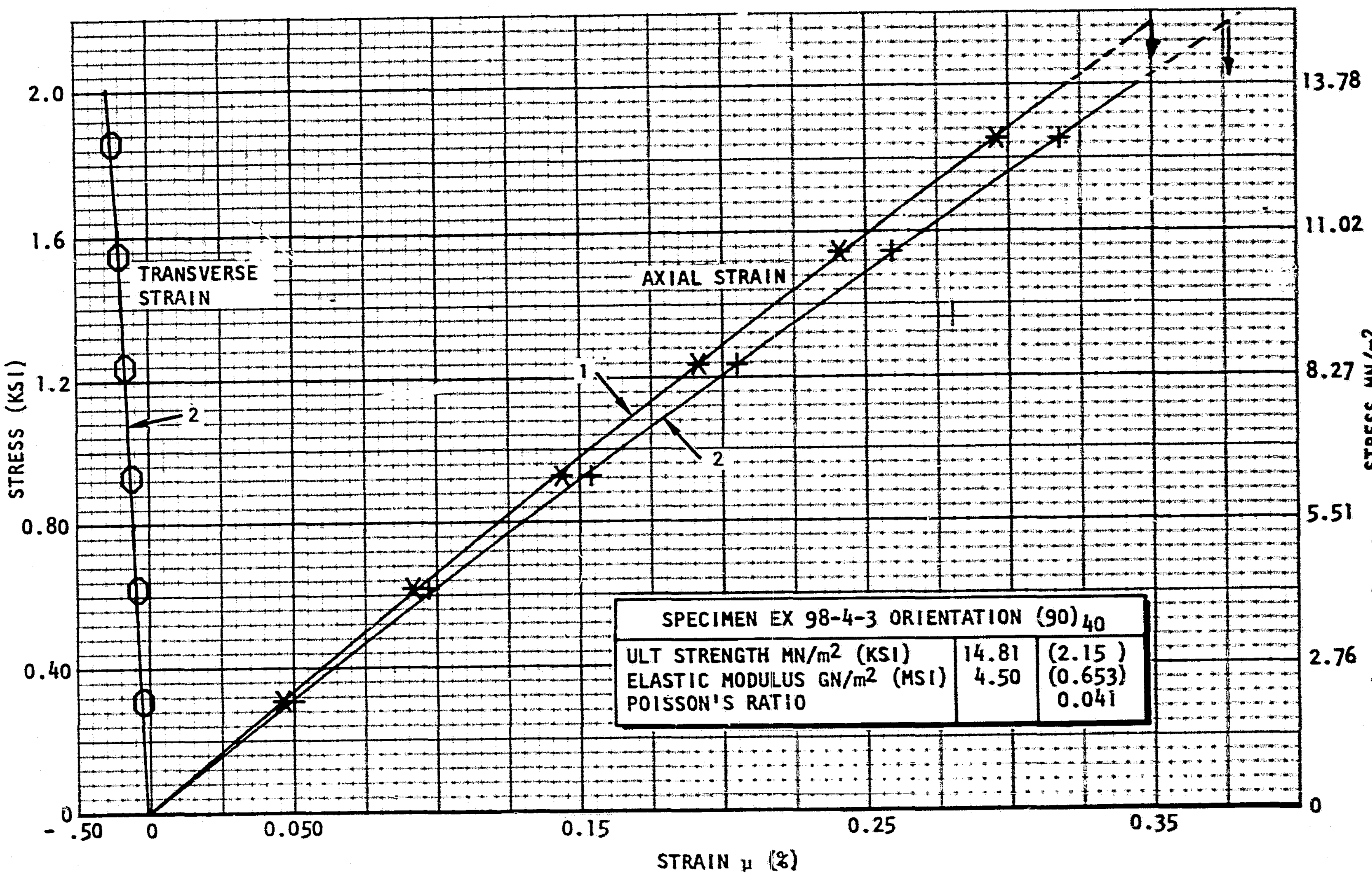

Figure B13. LARC-160/Celion 90° Stress/Strain Curves at 316 C (600 F)

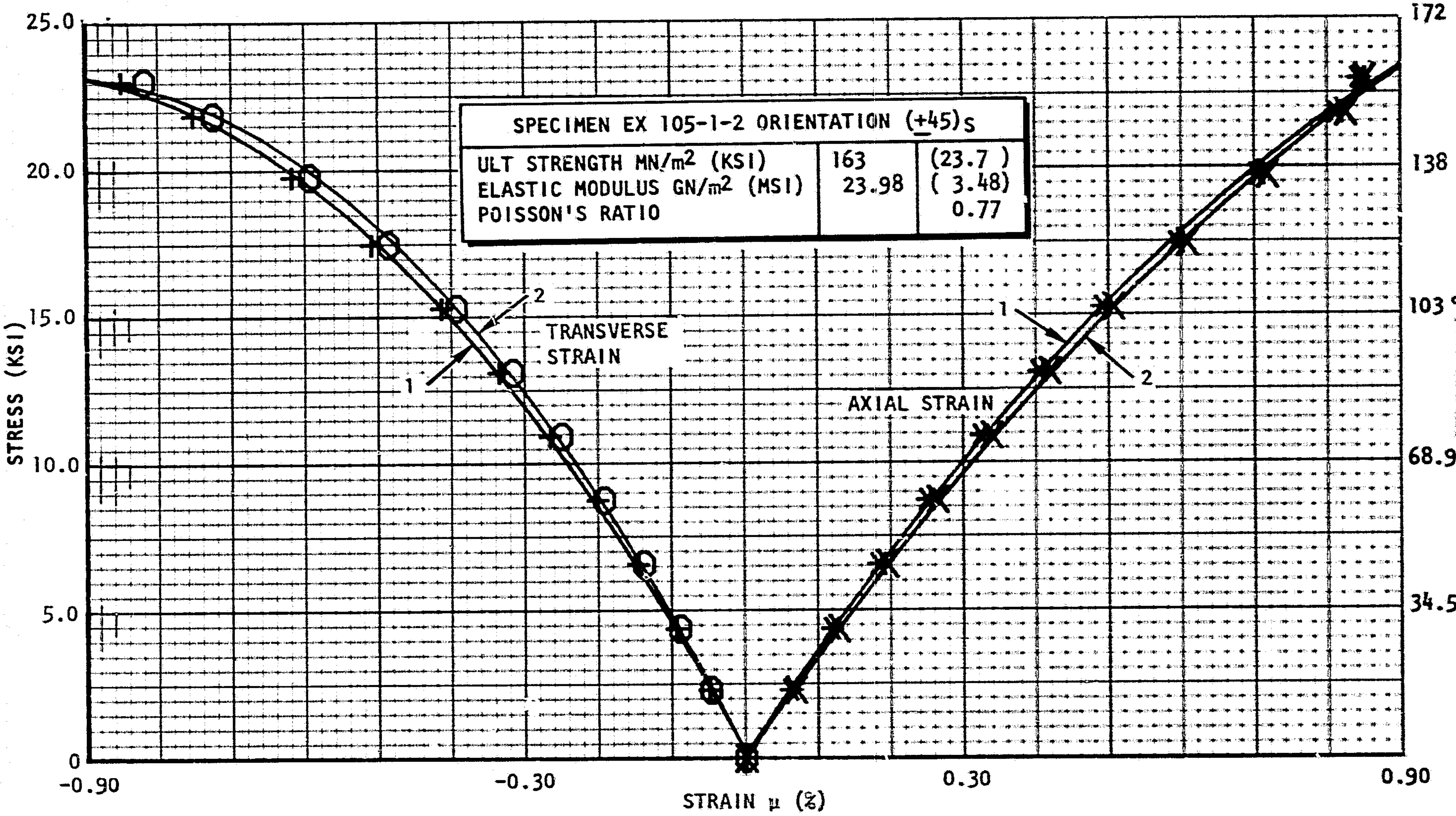

Figure B14. LARC-160/Celion $(\pm45)_S$ Stress/Strain Curves at RT.

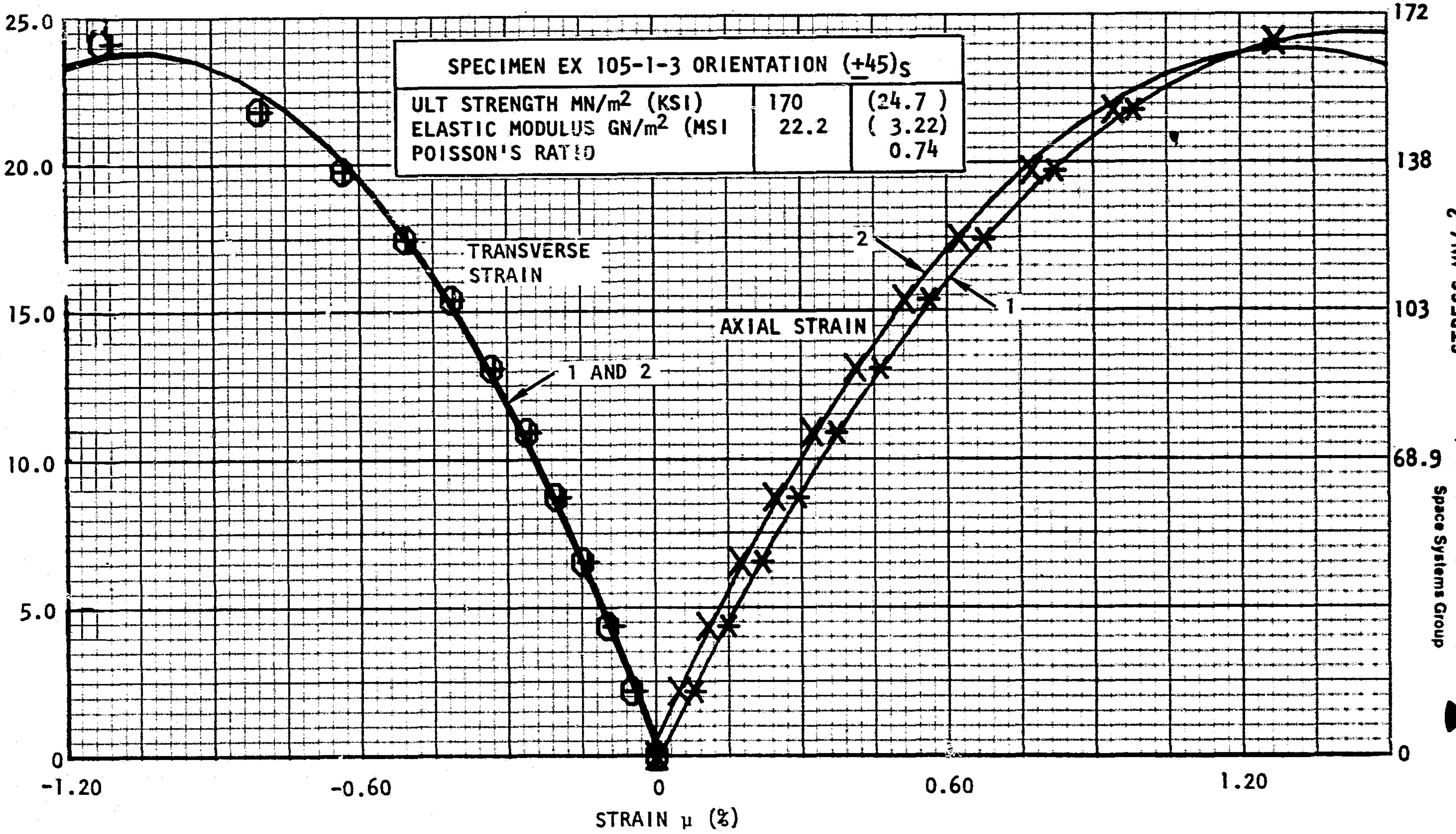

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Figure B15. LARC-160/Celion $(\pm 45)_S$ Stress/Strain Curves at RT.

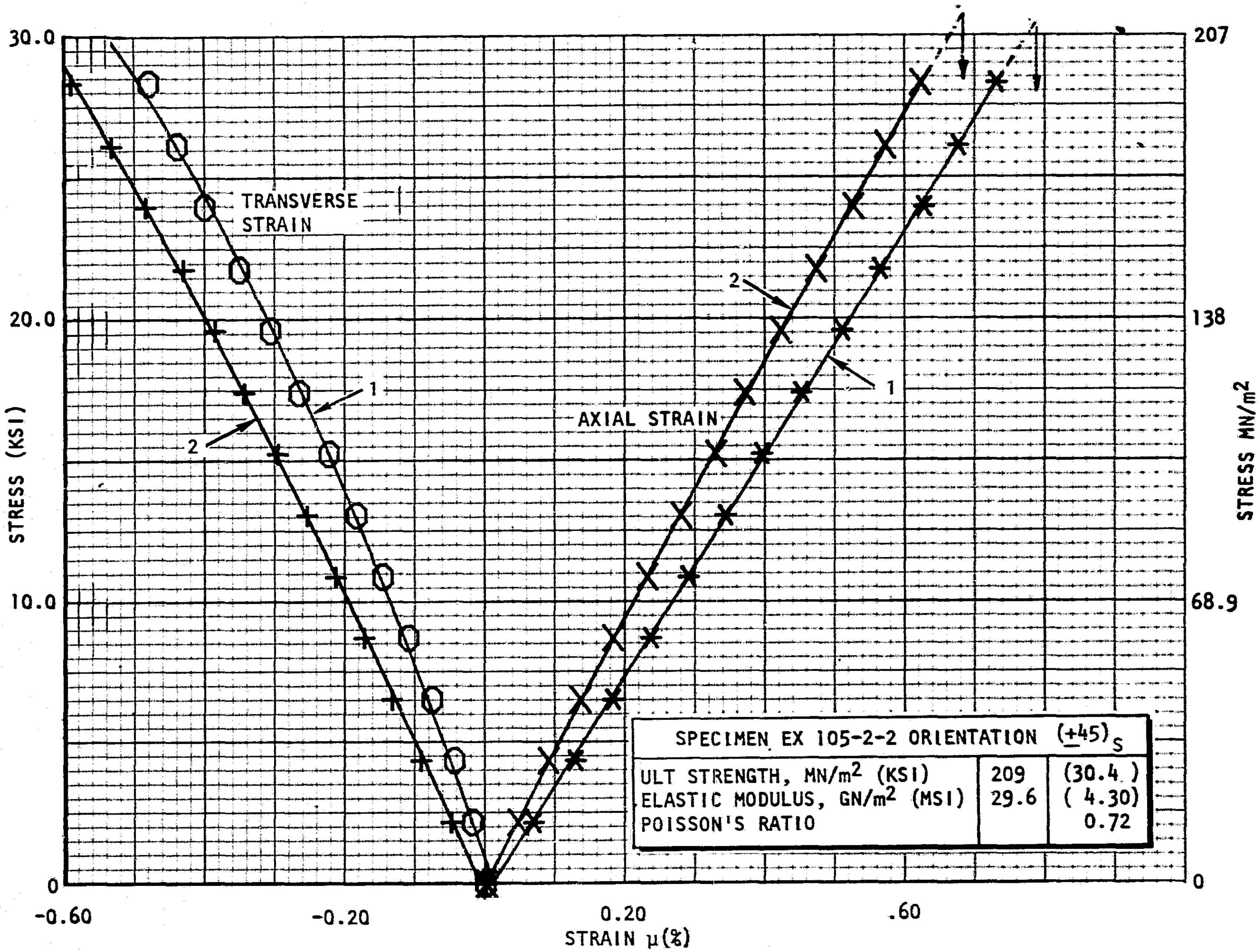

Figure B16. LARC-160/Celion $(\pm 45)_S$ Stress/Strain Curves at -132 C (-270 F)

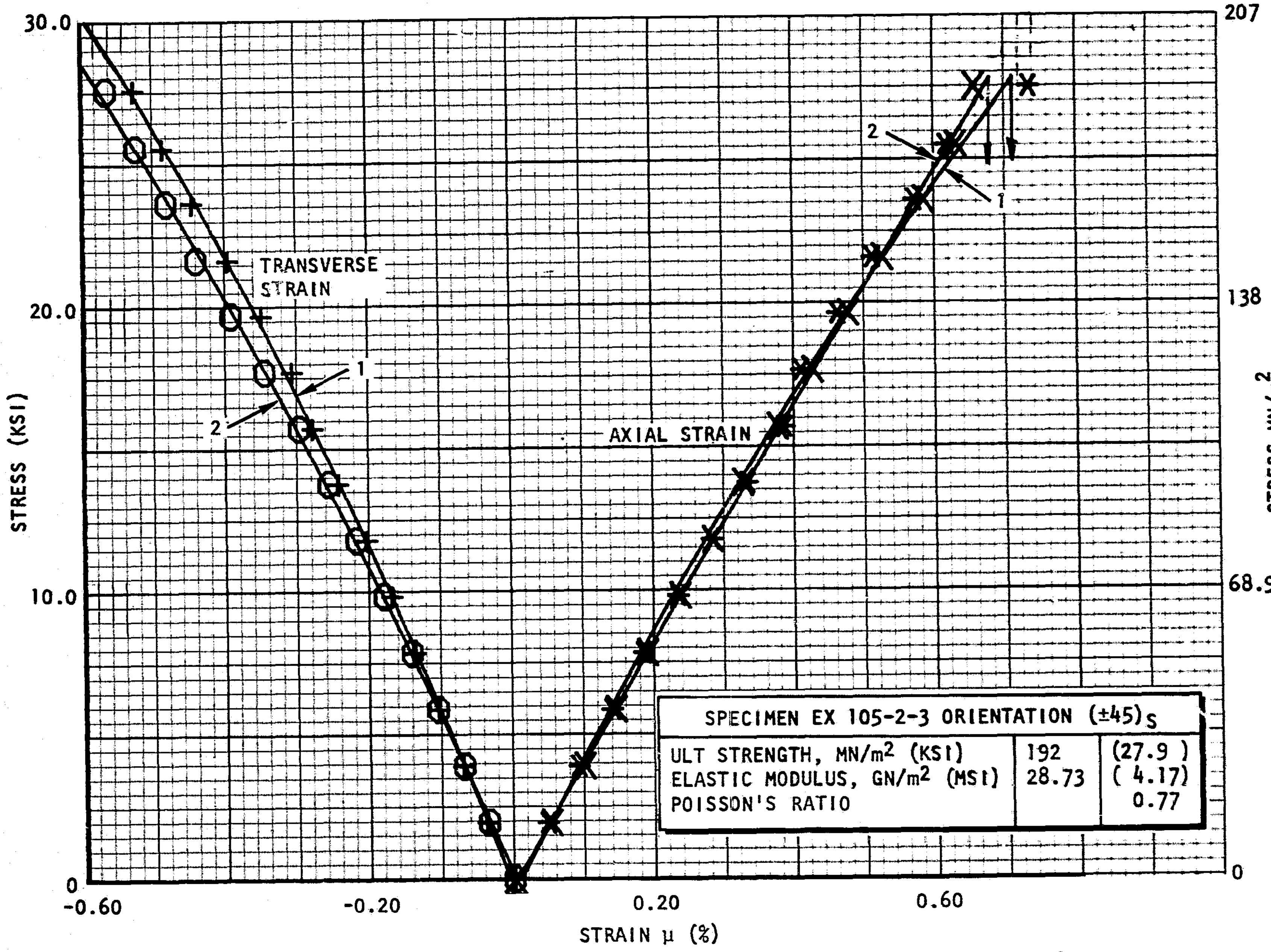

Figure B17. LARC-160/Celion (± 45)$_S$ Stress/Strain Curves at -132 C (-270 F)

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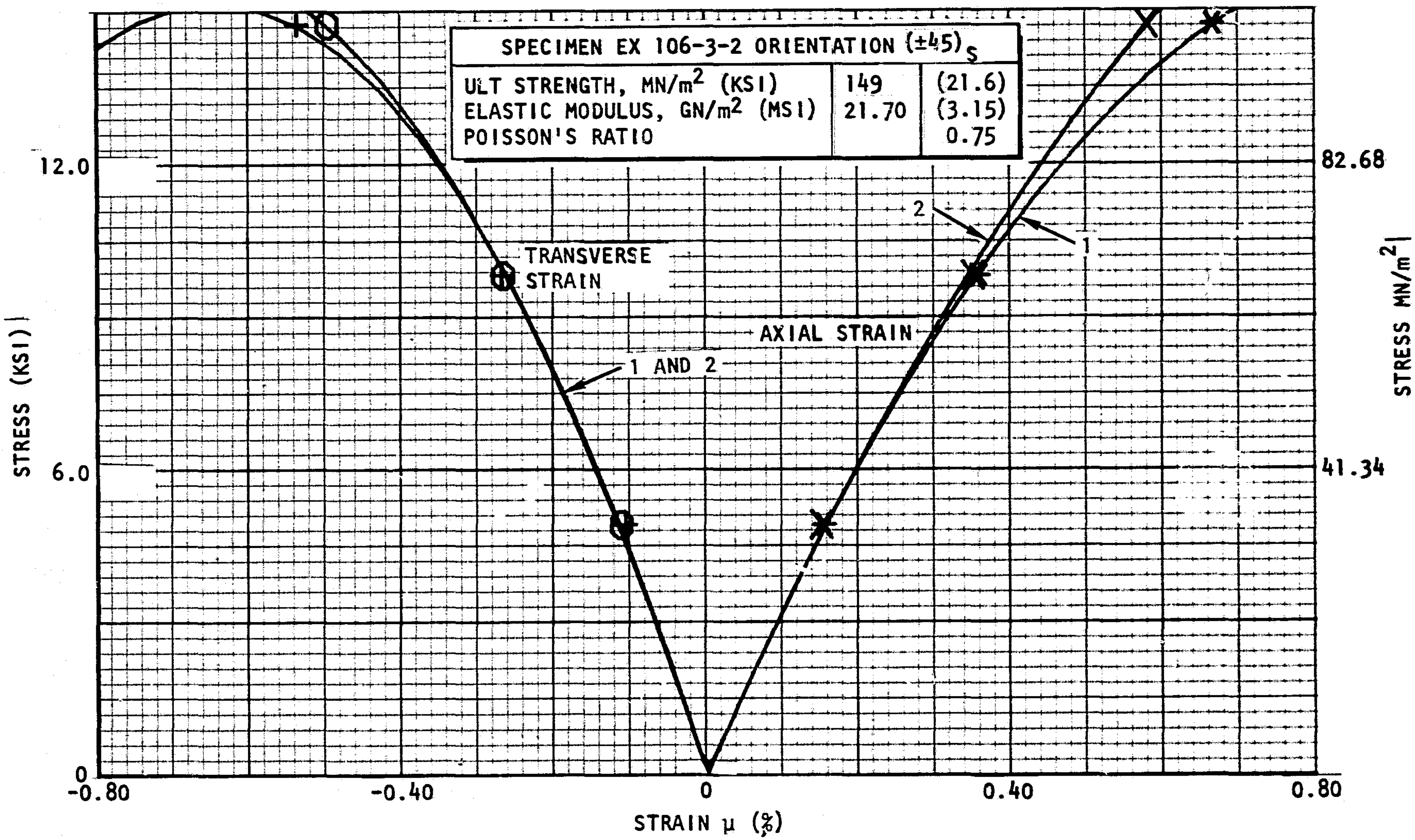

Figure B18. LARC-160/Celion ($\pm$45)$_S$ Stress/Strain Curves at 204 C (400 F)

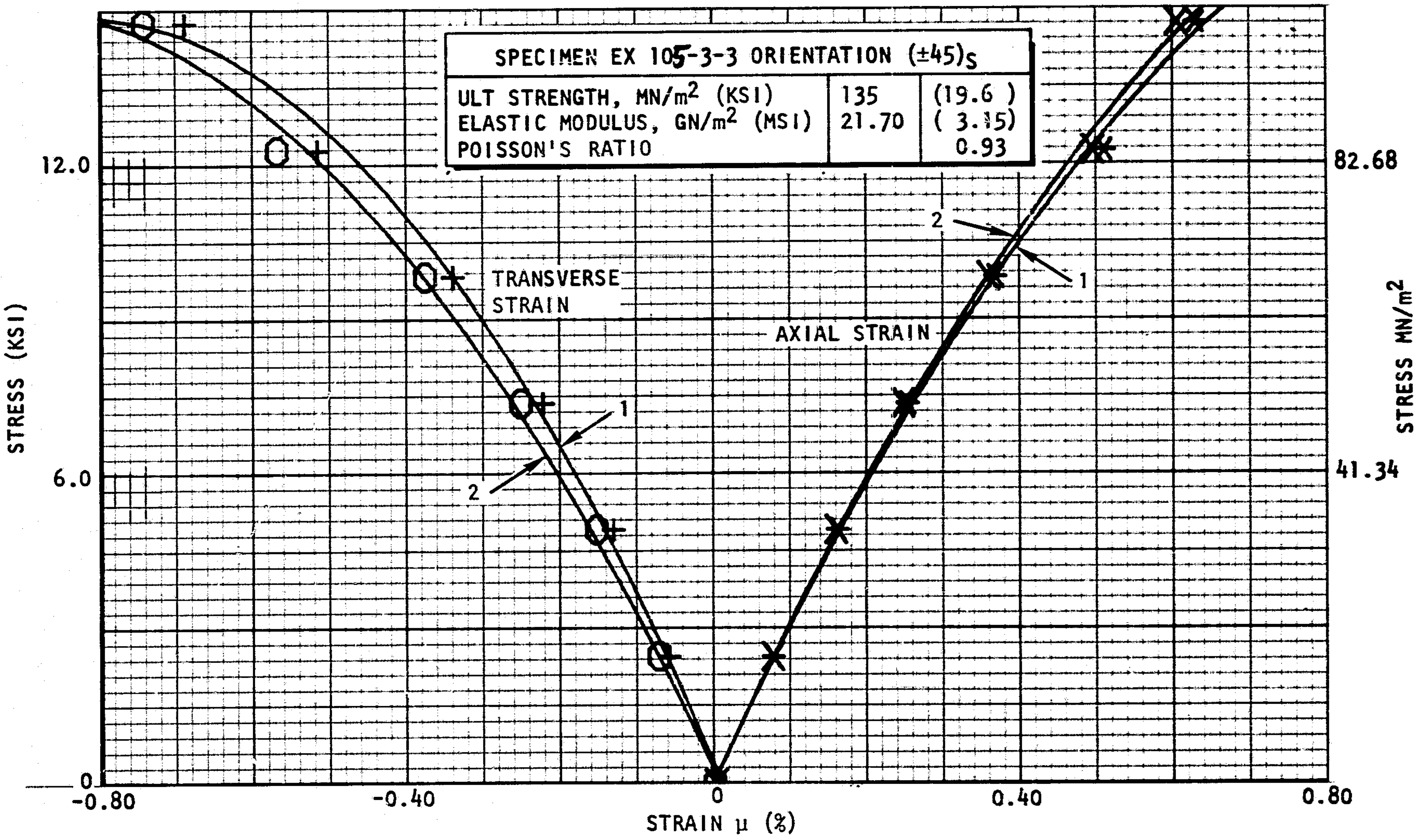

Figure B19. LARC-160/Celion ($\pm45)_S$ Stress/Strain Curves at 204 C (400 F)

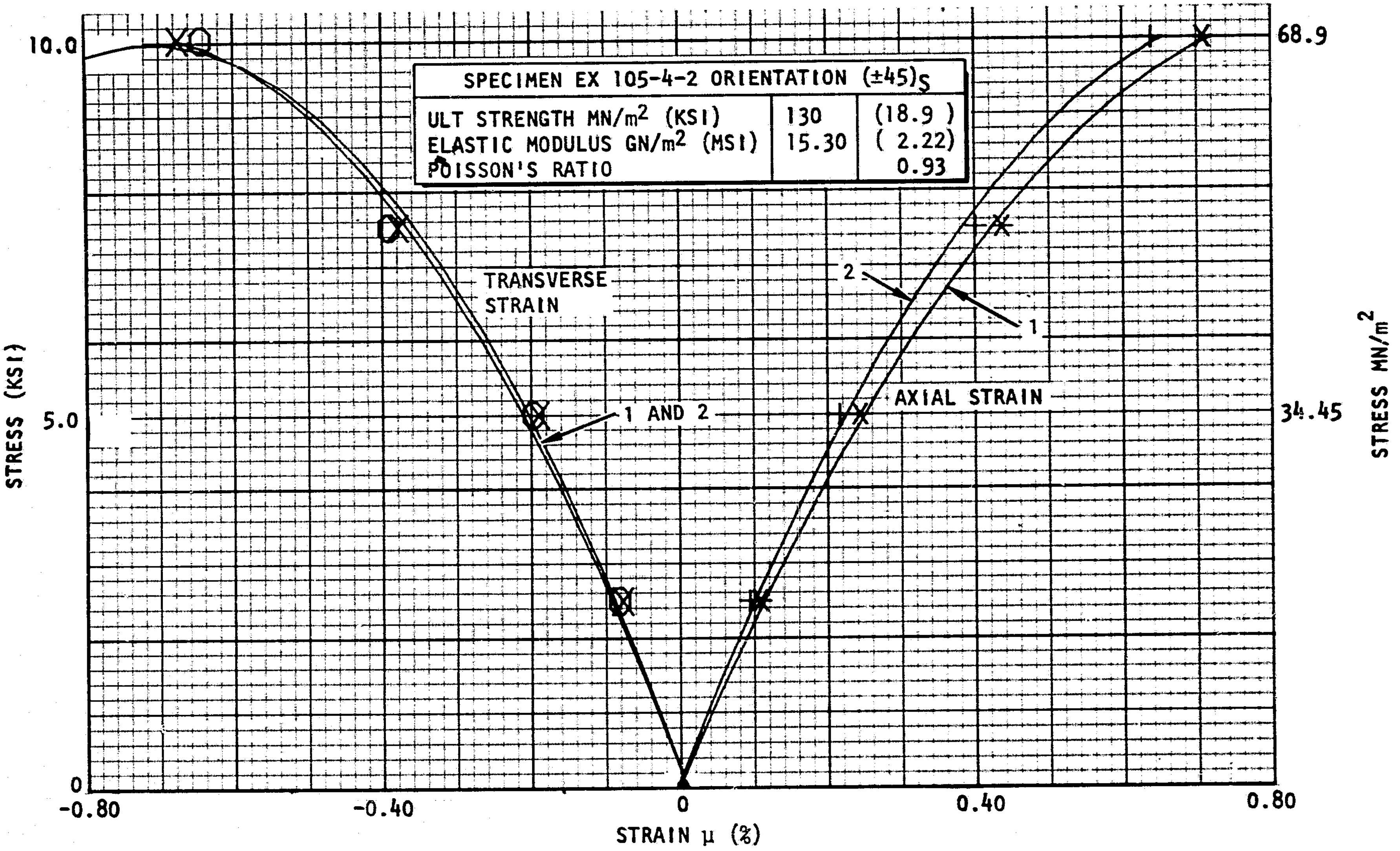

Figure B20. LARC/Celion $(\pm 45)_S$ Stress/Strain Curves at 316 C (600 F)

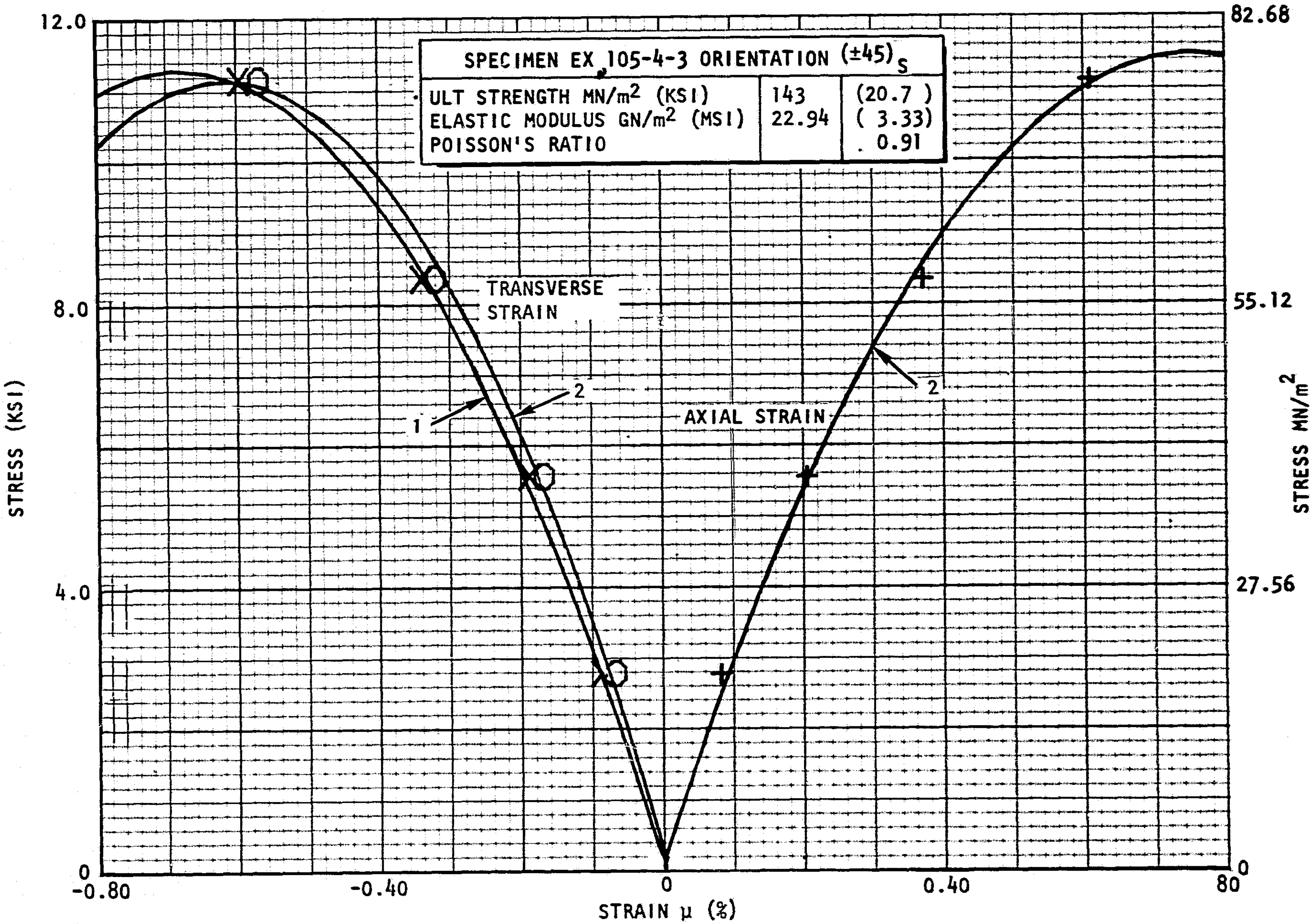

Figure B21. LARC-160/Celion $(\pm 45)_S$ Stress/Strain Curves at 316 C (600 F)

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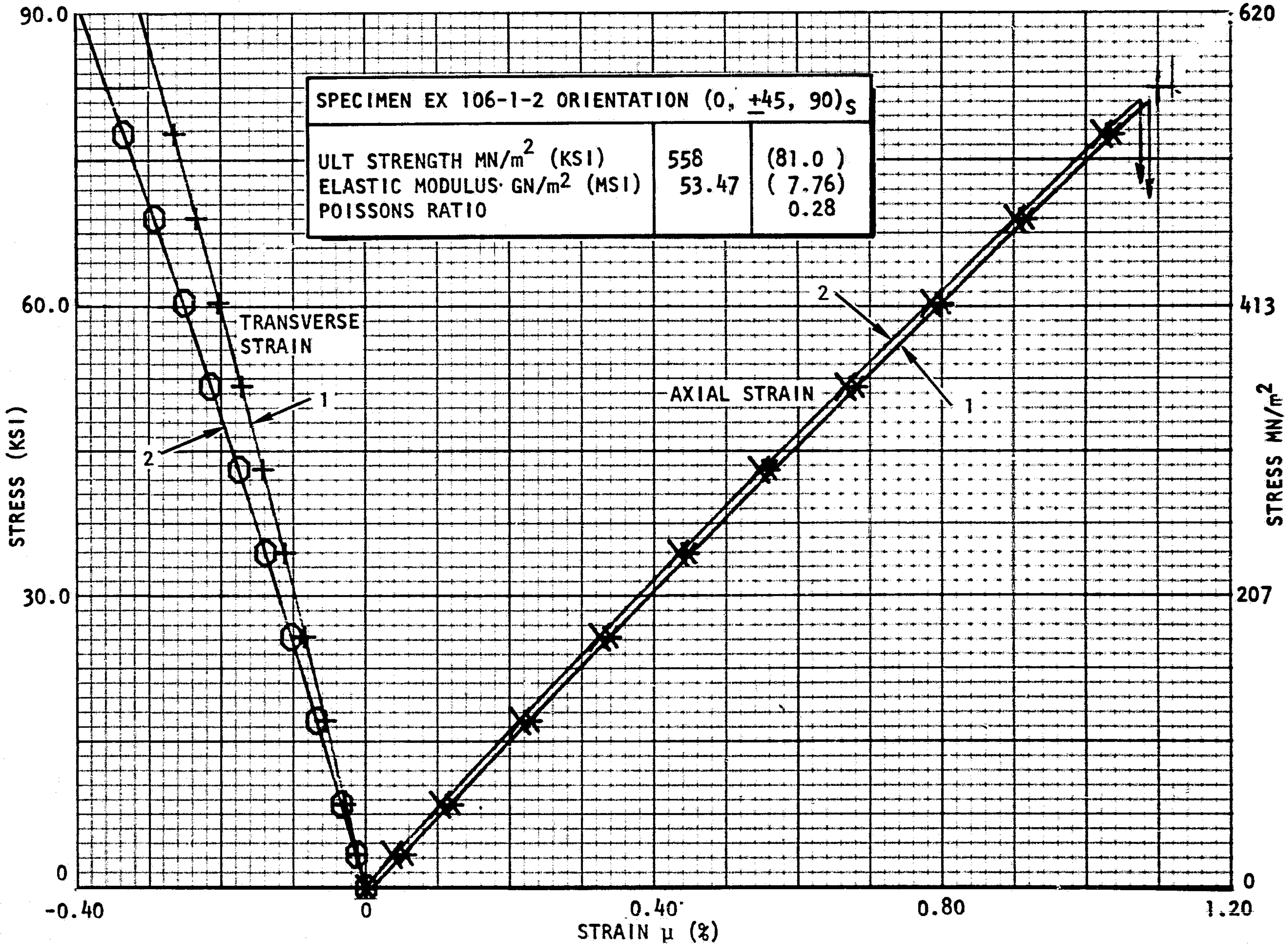

Figure B22. LARC-160/Celion (0, ±45, 90)$_S$ Stress/Strain Curves at RT

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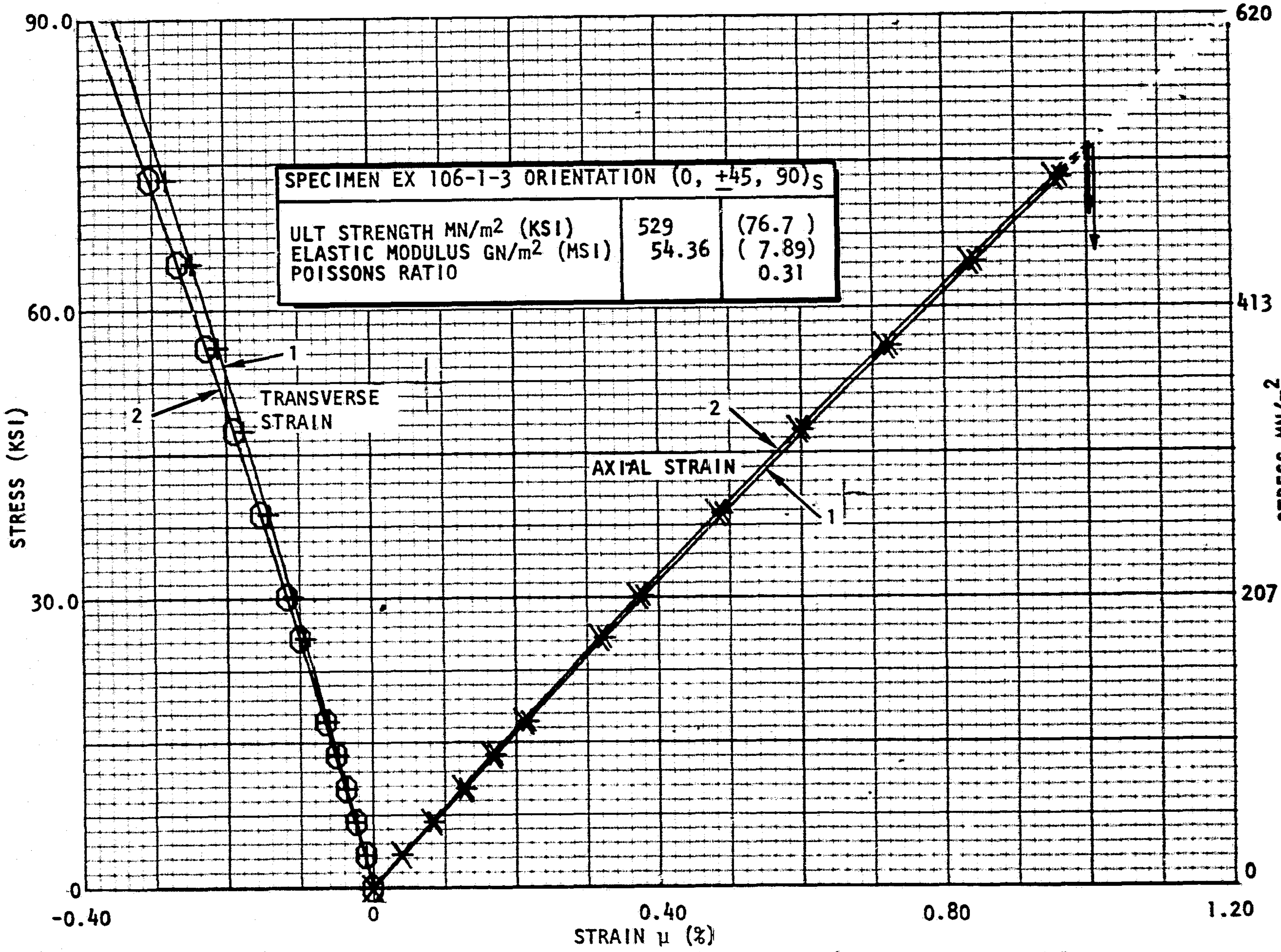

Figure B23. LARC-160/Celion (0, ±45, 90)$_S$ Stress/Strain Curves at RT

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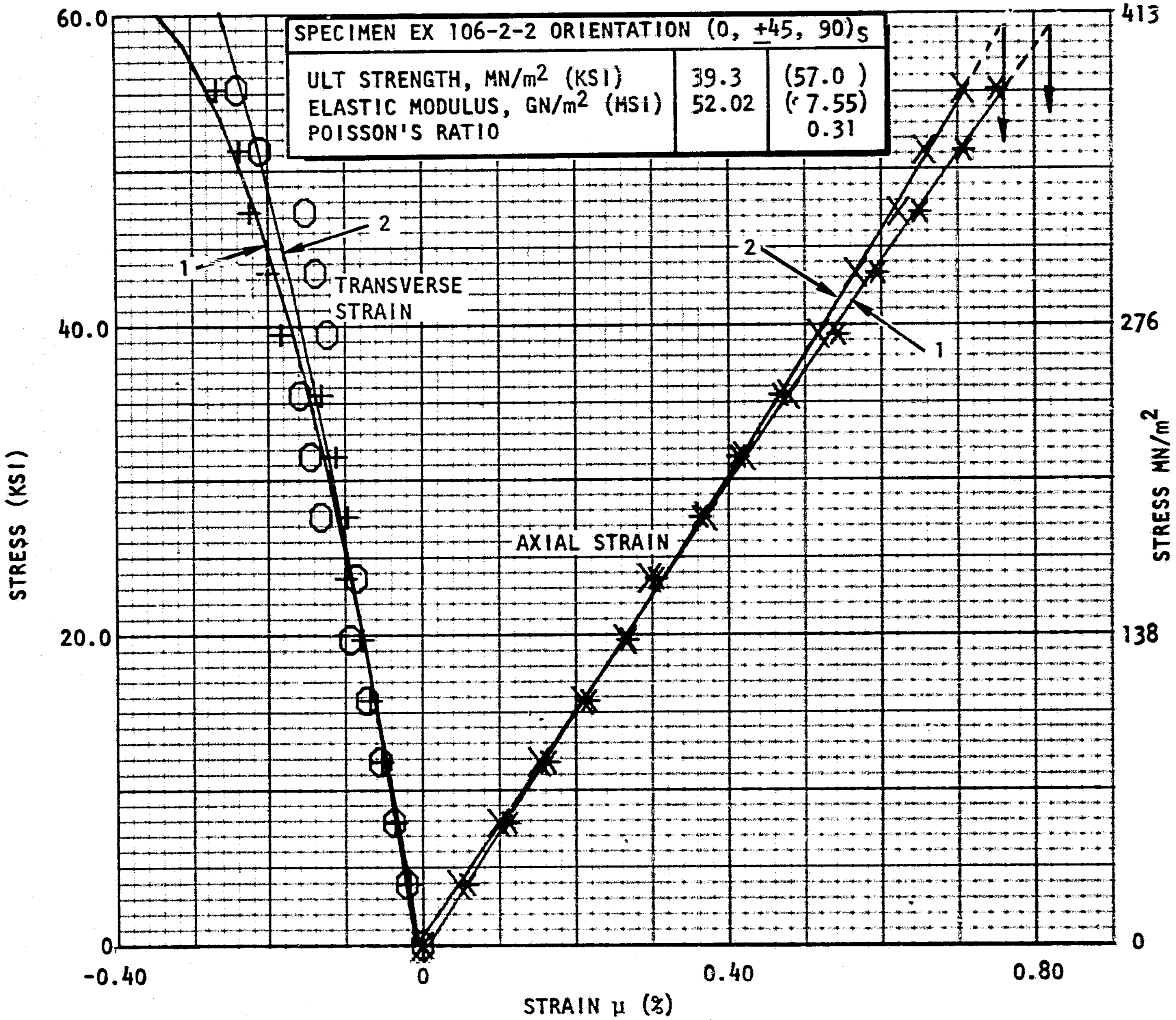

Figure B24. LARC-160/Celion (0, ±45, 90)$_S$ Stress/Strain Curves at -132C (-270 F)

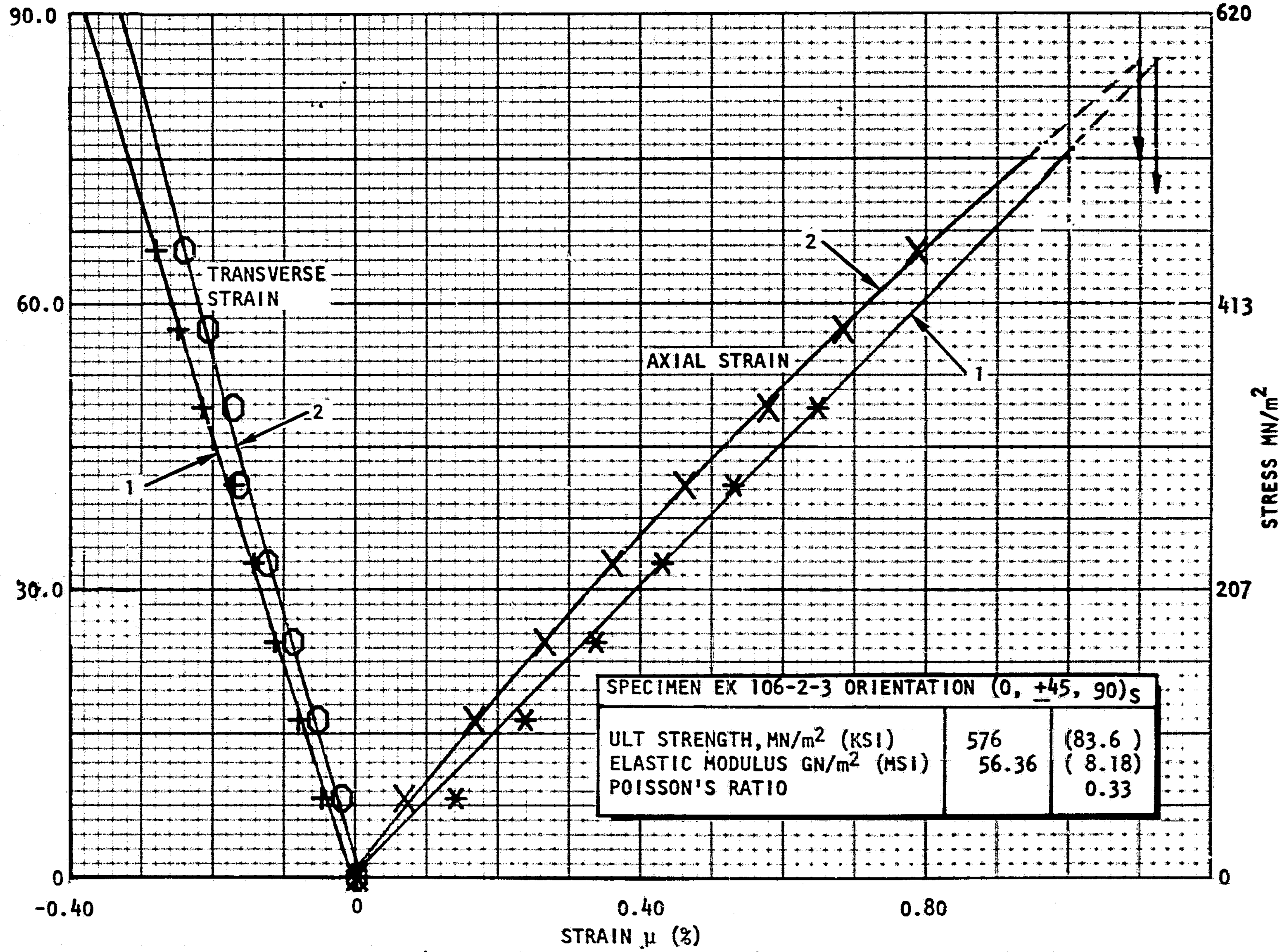

Figure B25. LARC-160/Celion (0, $\pm$45, 90)$_S$ Stress/Strain Curves at -132 C (-270 F)

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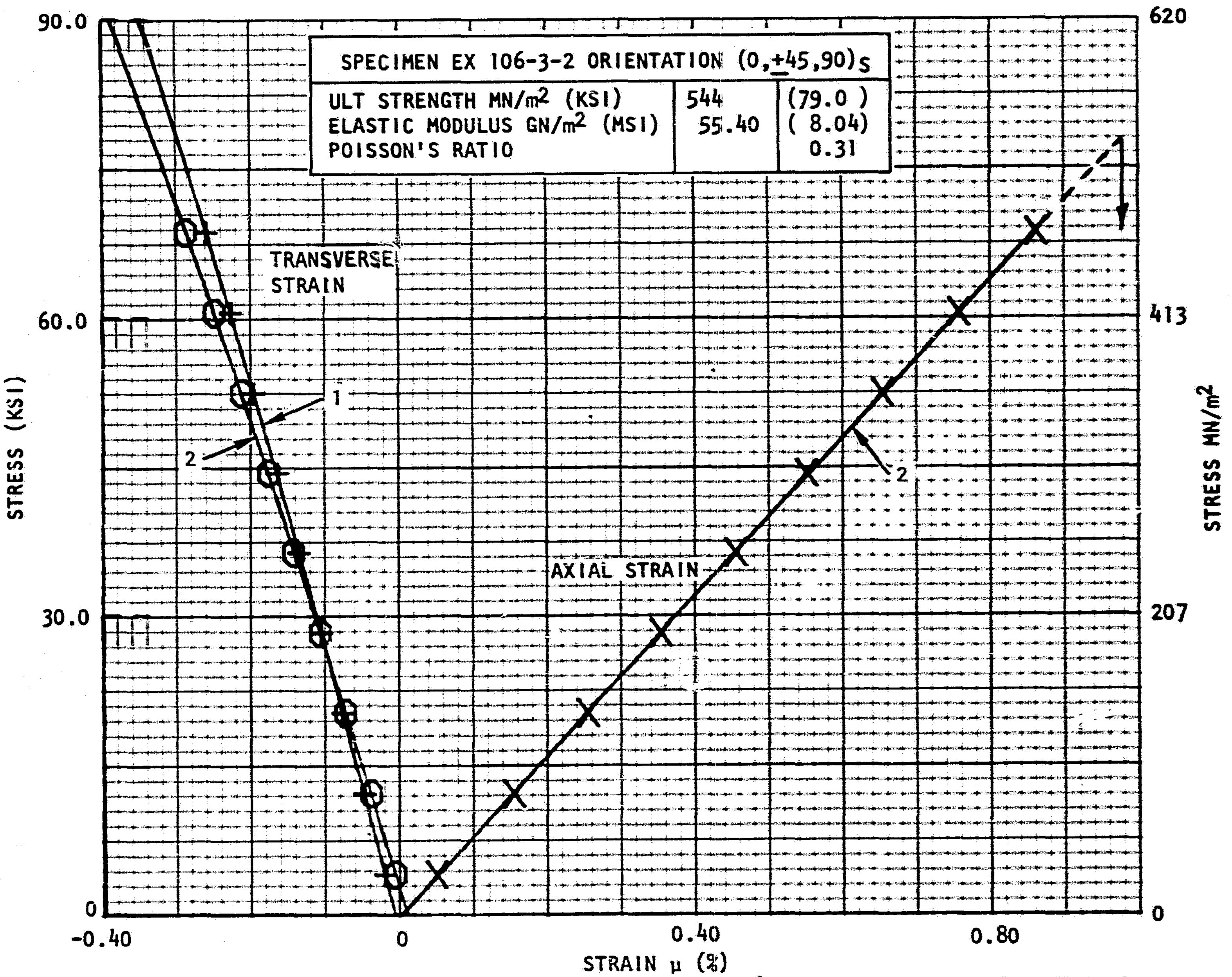

Figure B26. LARC-160/Celion $(0, \pm45, 90)_S$ Stress/Strain Curves at 204 C (400 F)

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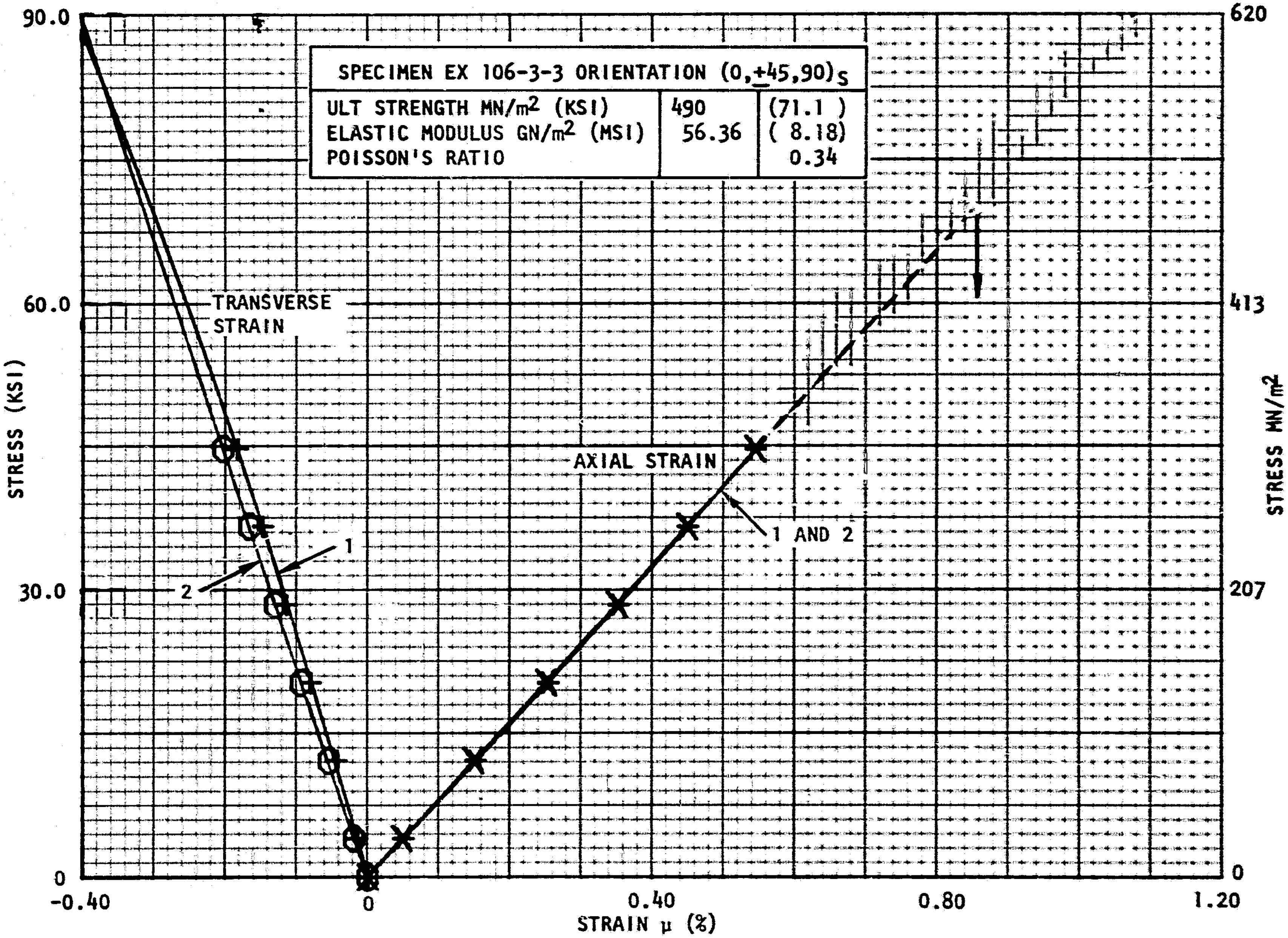

Figure B27. LARC-160/Celion $(0, \pm45, 90)_S$ Stress/Strain Curves at 204 C (400 F)

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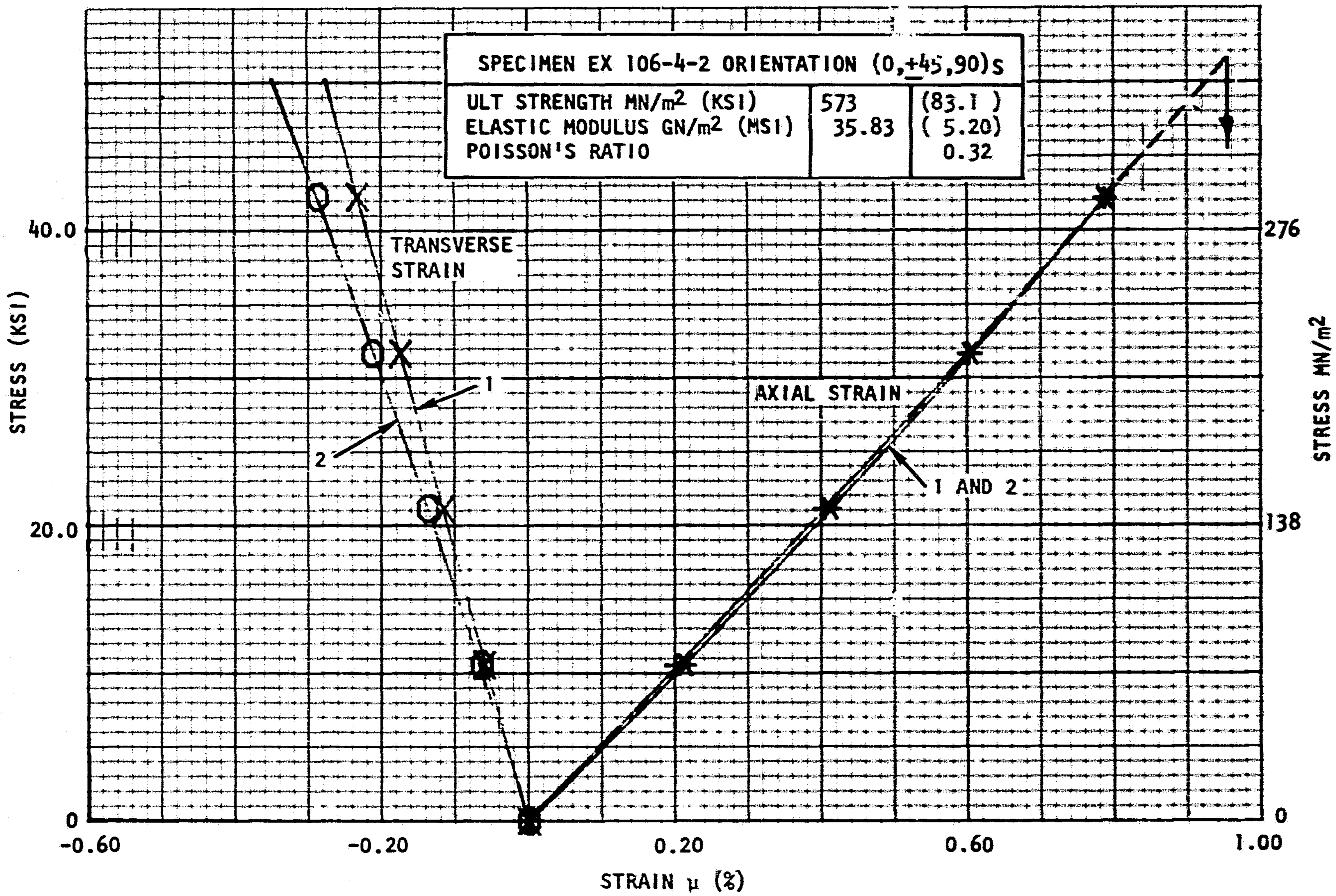

Figure B28. LARC-160/Celion (0, ±45, 90)S Stress/Strain Curves at 316 C (600 F)

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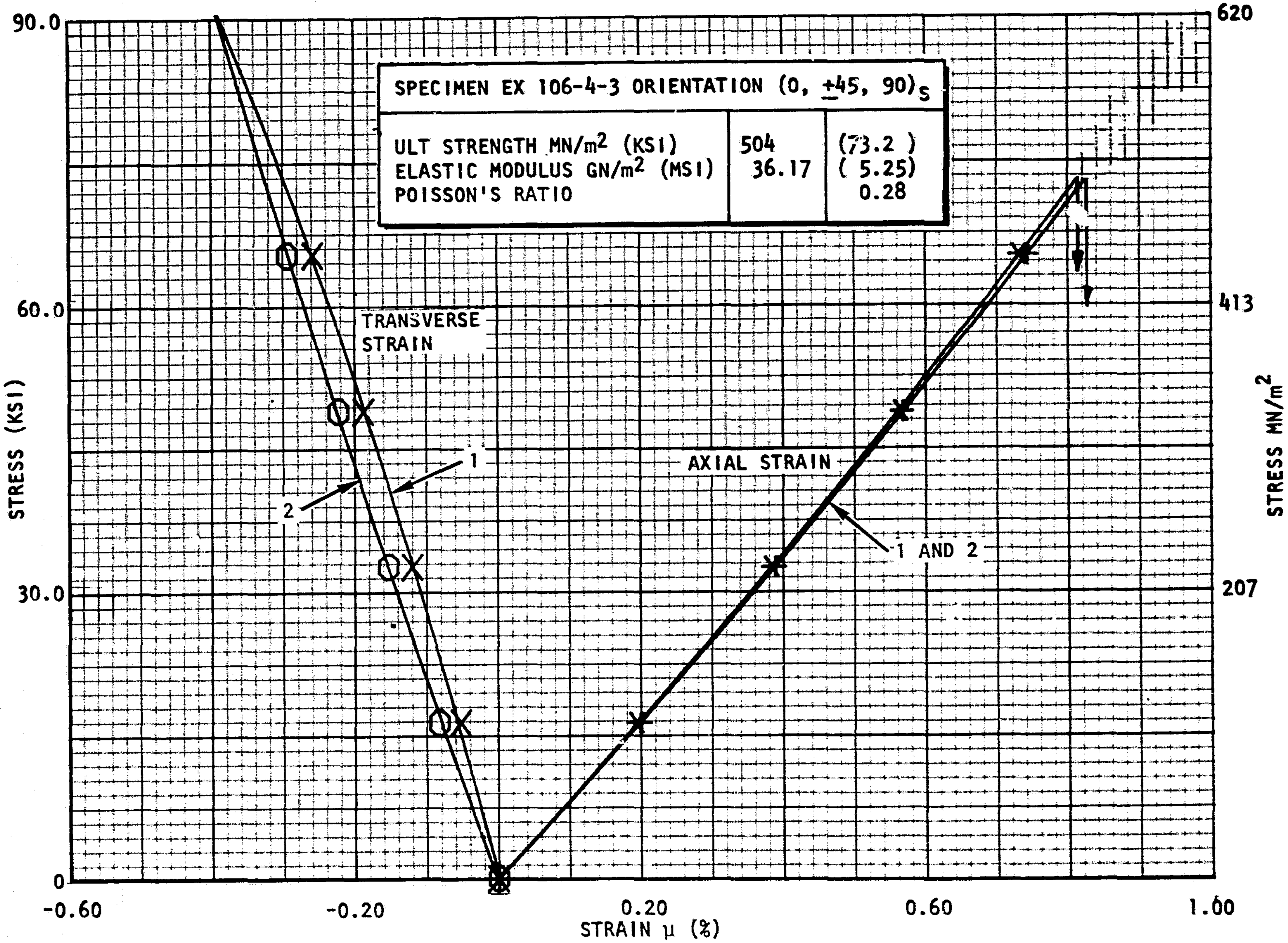

Figure B29. LARC-160/Celion (0, $\pm$45, 90)$_S$ Stress/Strain Curves at 316 C (600 F)

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TENSION BEAM
CURVES

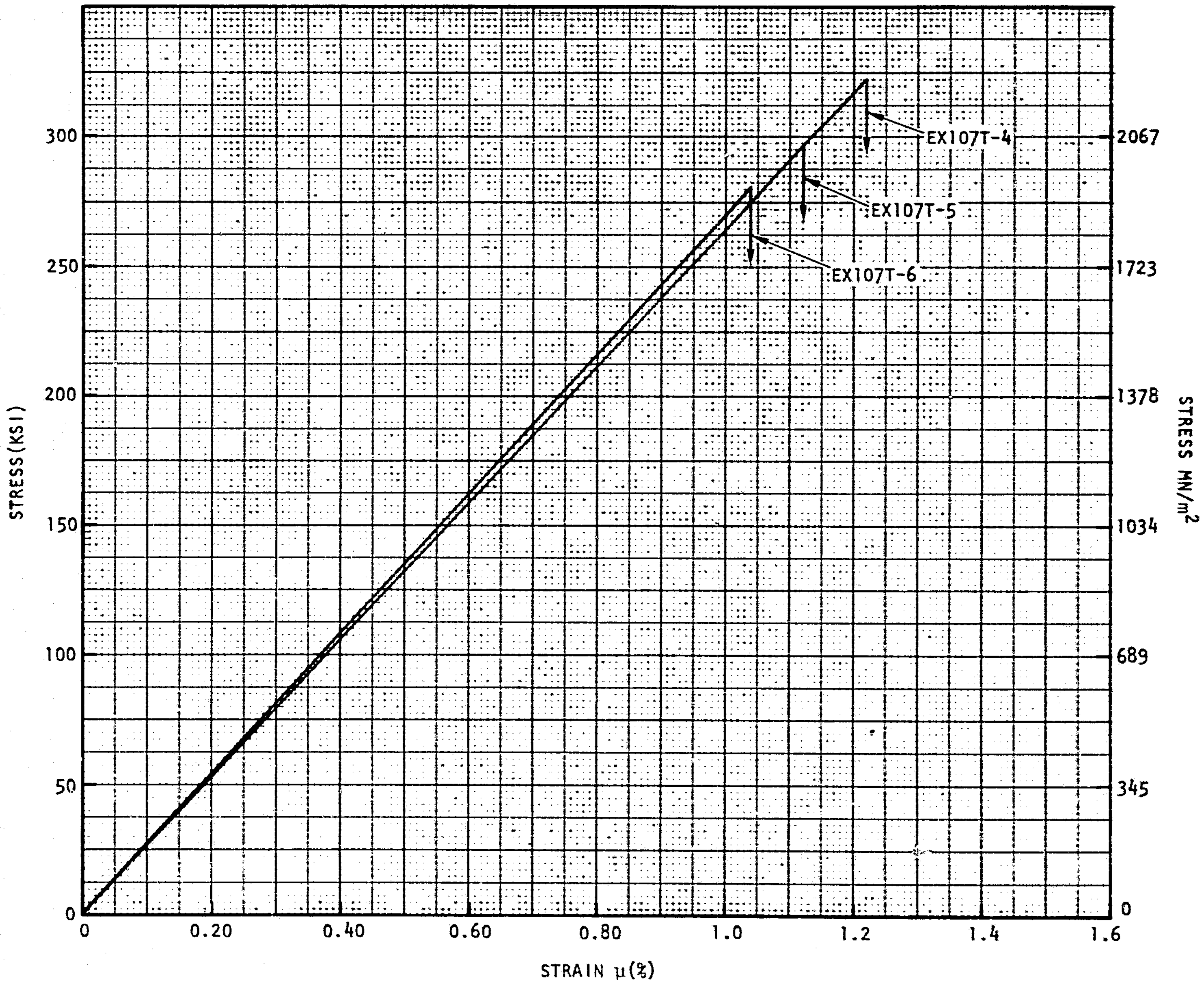

Figure B30. Tensile Stress/Strain Characteristics of $(0)_5$ Parallel LARC-160/Celion Laminates at—132 C(--270 F) Beam Test

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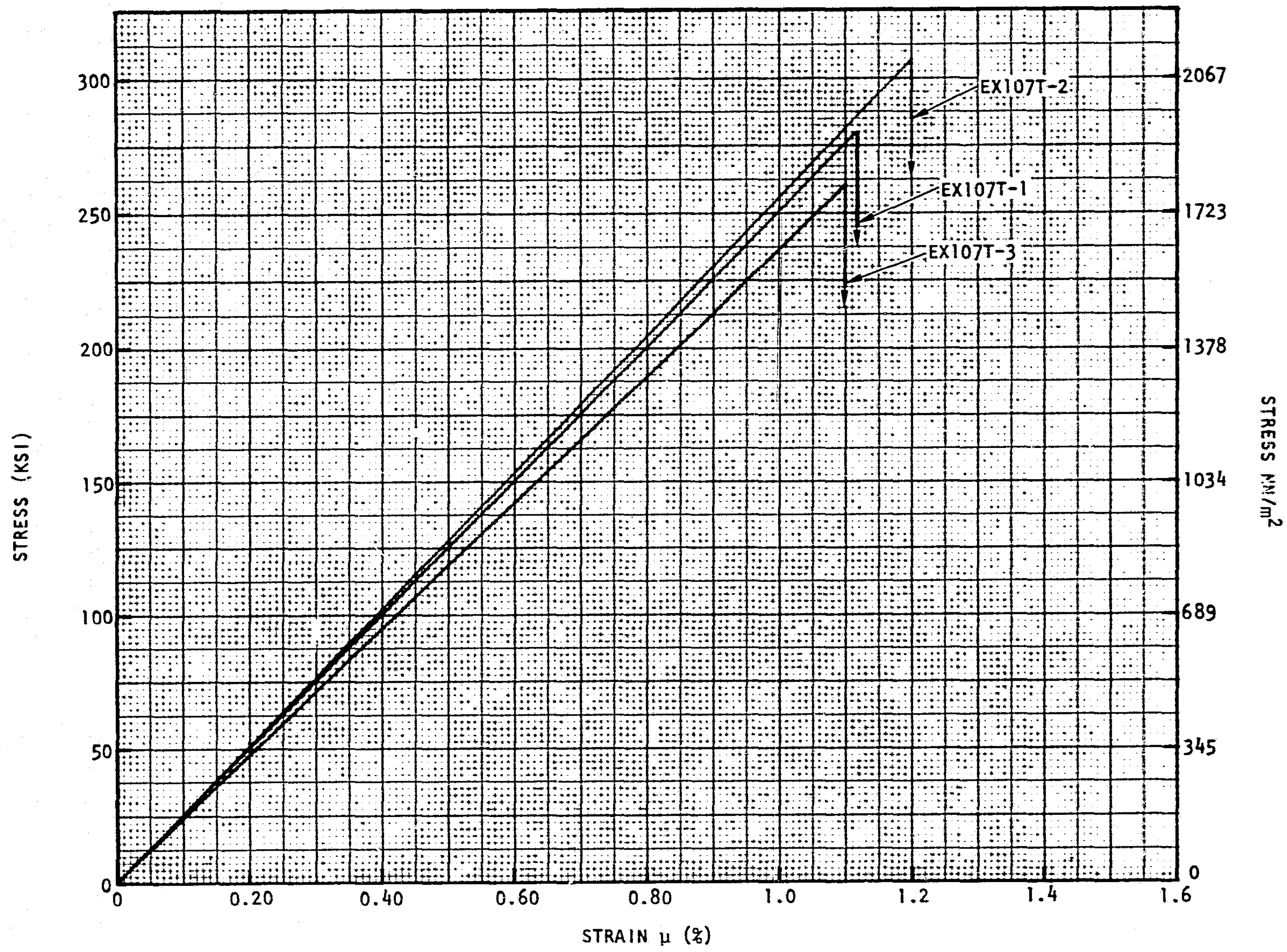

Figure B31. Tensile Stress/Strain Characteristics of (0)5 Parallel LARC-160/Celion Laminates at RT—Beam Test

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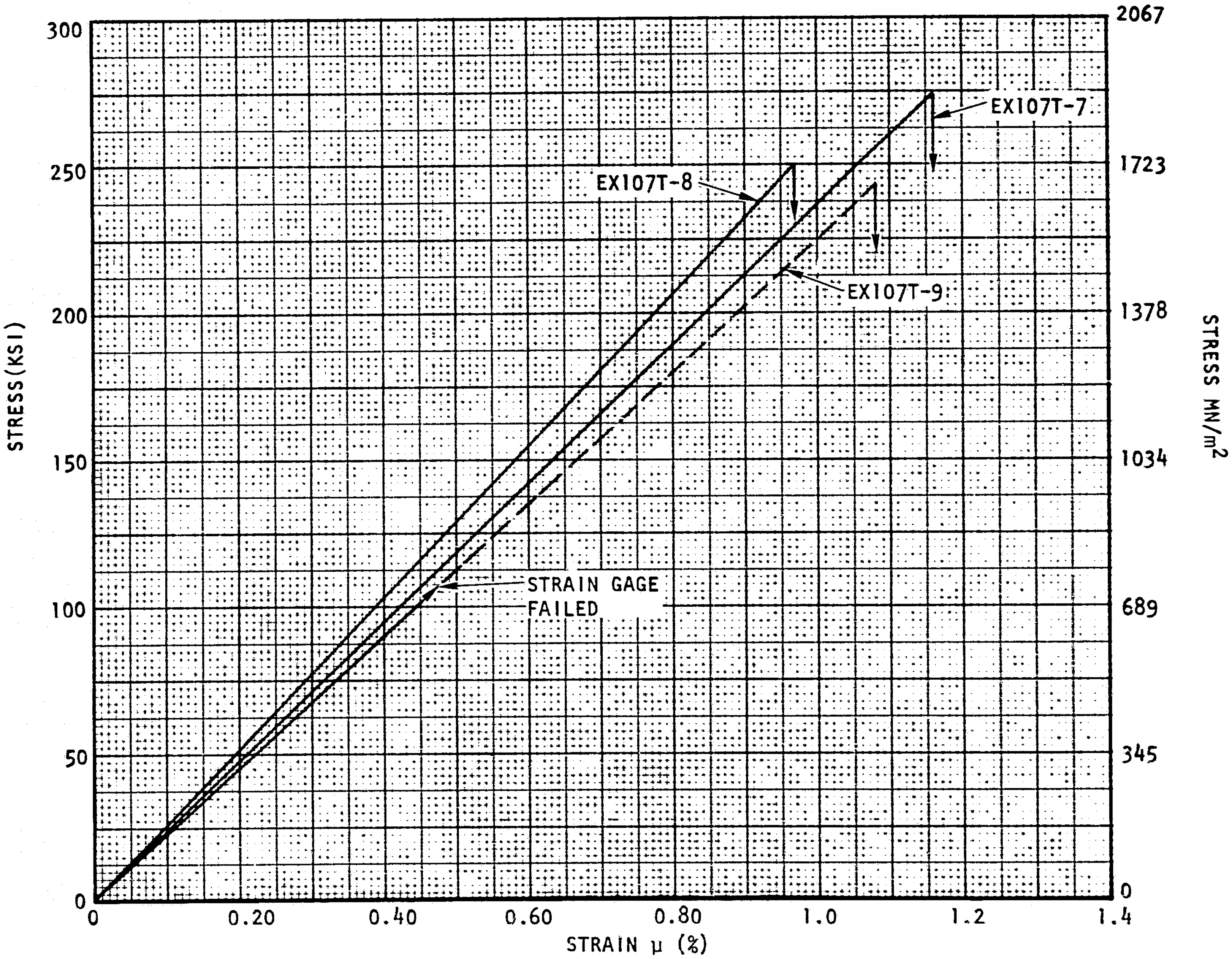

Figure B32. Tensile Stress/Strain Characteristics of $(0)_5$ Parallel LARC-160/celion Laminates at 204 C(400 F)—Beam Test

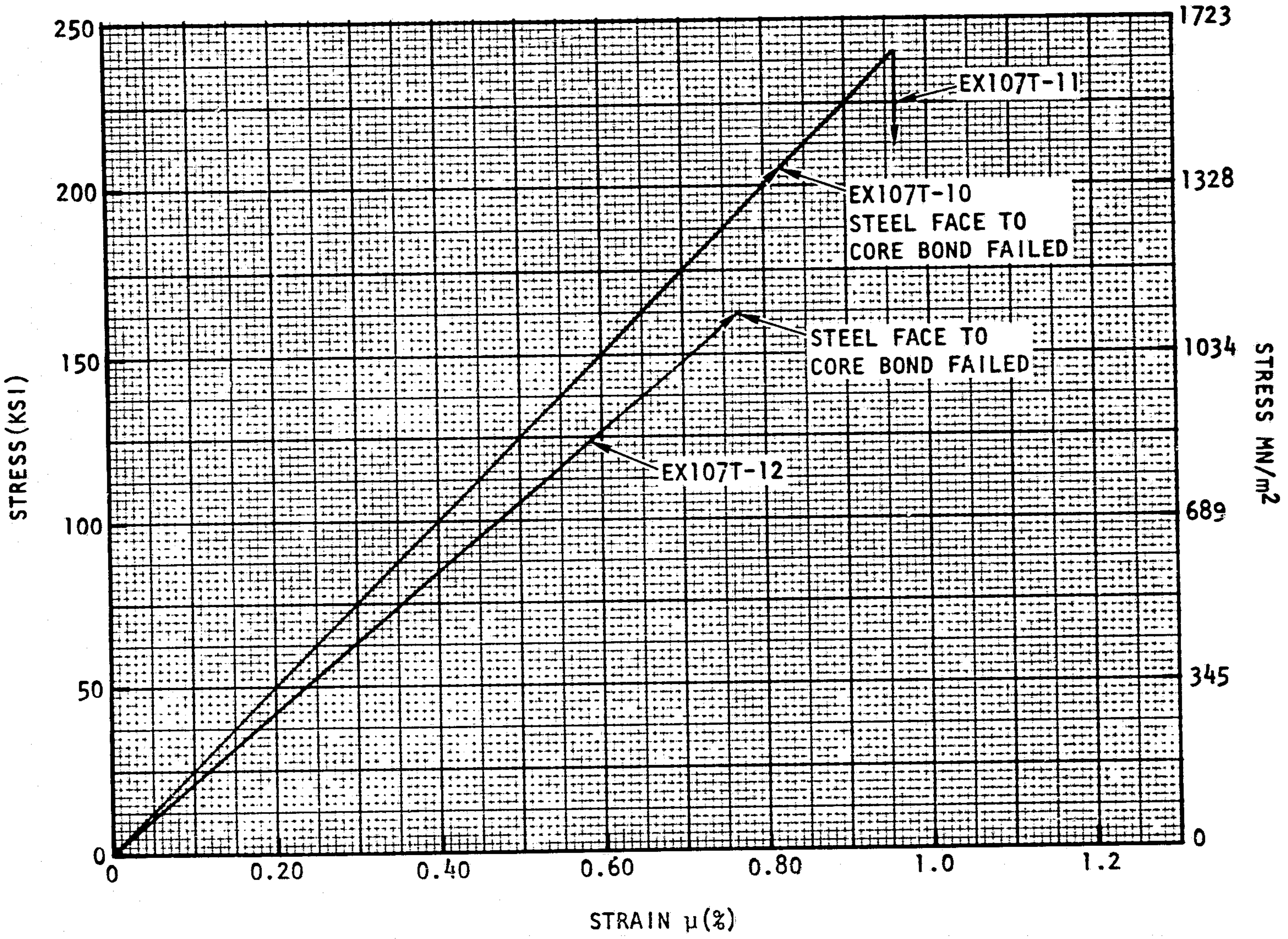

Figure B33. Tensile Stress/Strain Characteristics of $(0)_5$ Parallel LARC-160/Celion Laminates at 316 C (600 F) - Beam Test

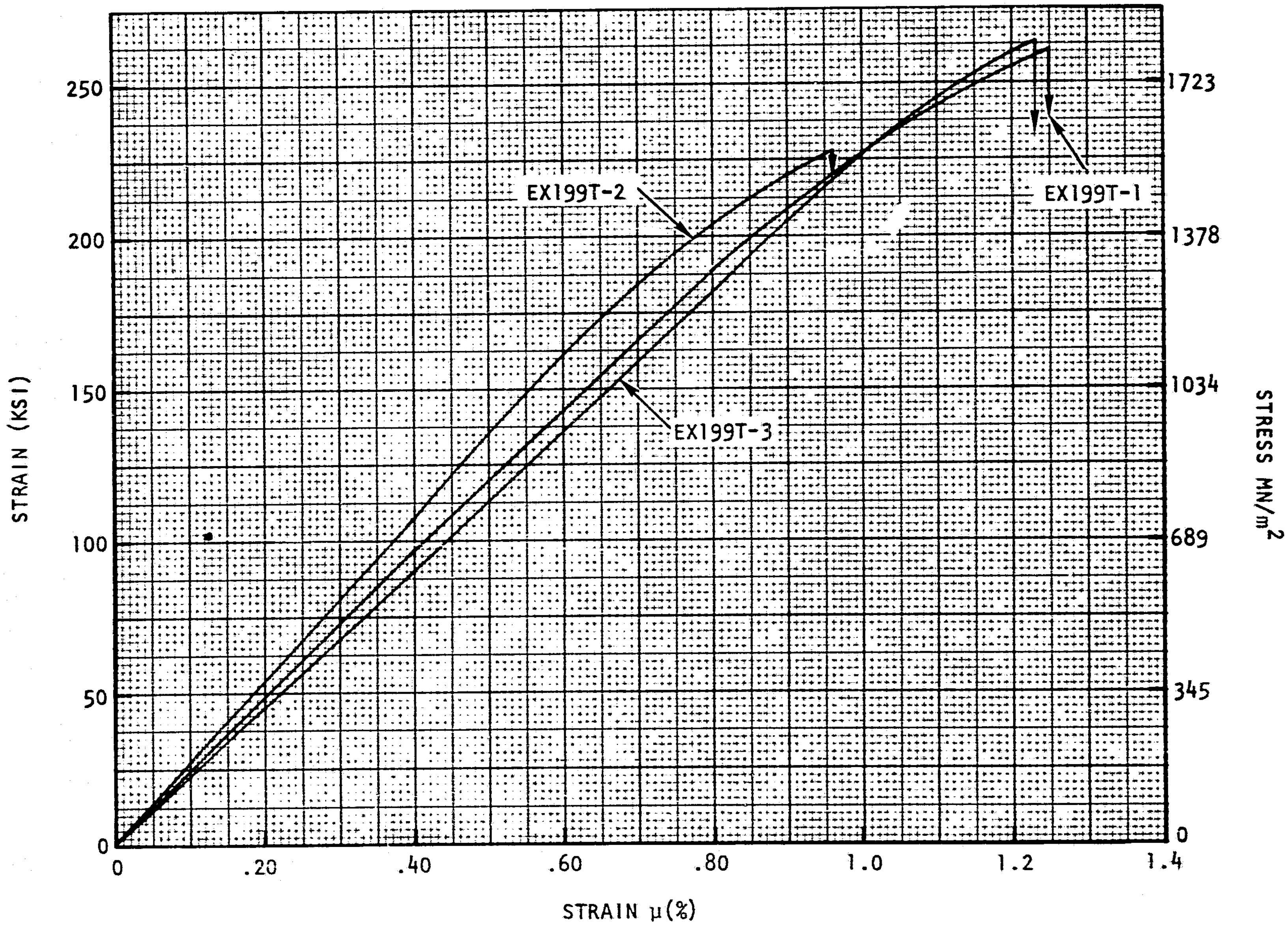

Figure B34. Tensile Stress/Strain Characteristics of (0)5, Parallel LARC-160/Celion Laminates Aged for 125 Hours at 316 C (600 F), Beam Test at - 132 C (-270 F)

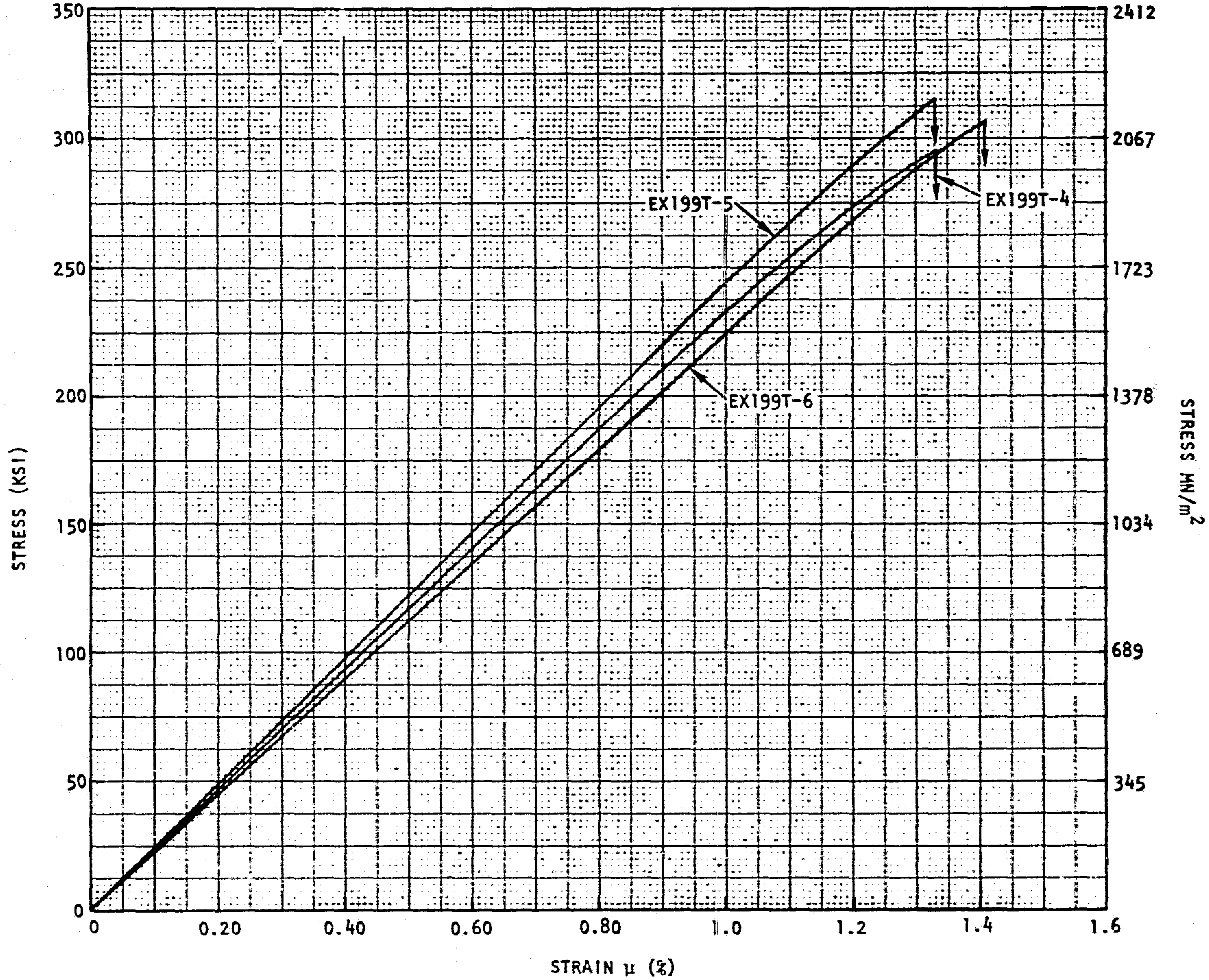

Figure B35. Tensile Stress/Strain Characteristics of $(0)_5$ Parallel Oriented LARC-160/Celion Laminates Aged 125 Hours at 316 C (600 F), Beam Test at RT

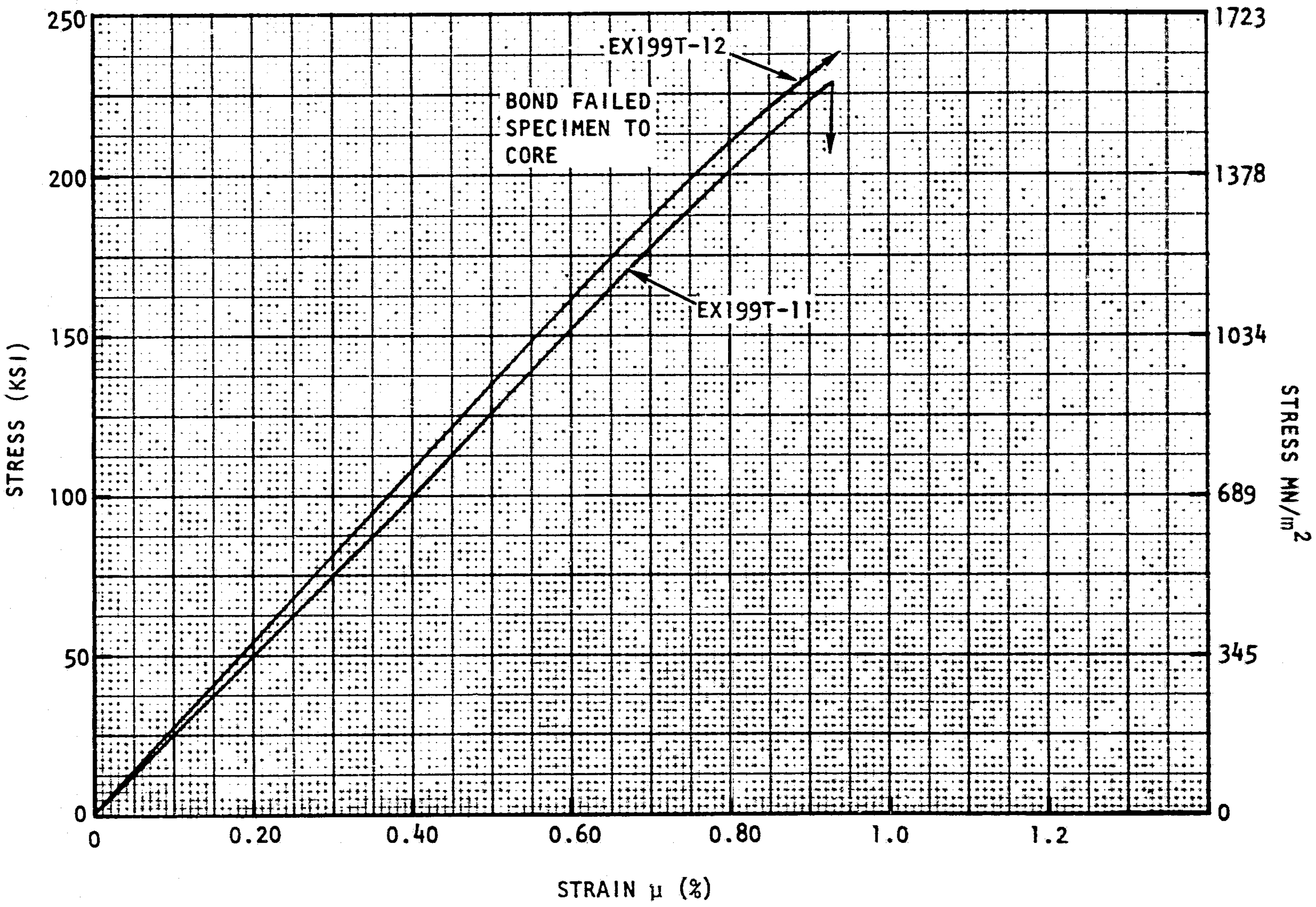

Figure B36 Tensile Stress/Strain Characteristics of $(0)_5$ Parallel Oriented LARC-160/Celion Laminates Aged 125 Hours at 316 C (600 F), Beam Test at 204 C (400 F)

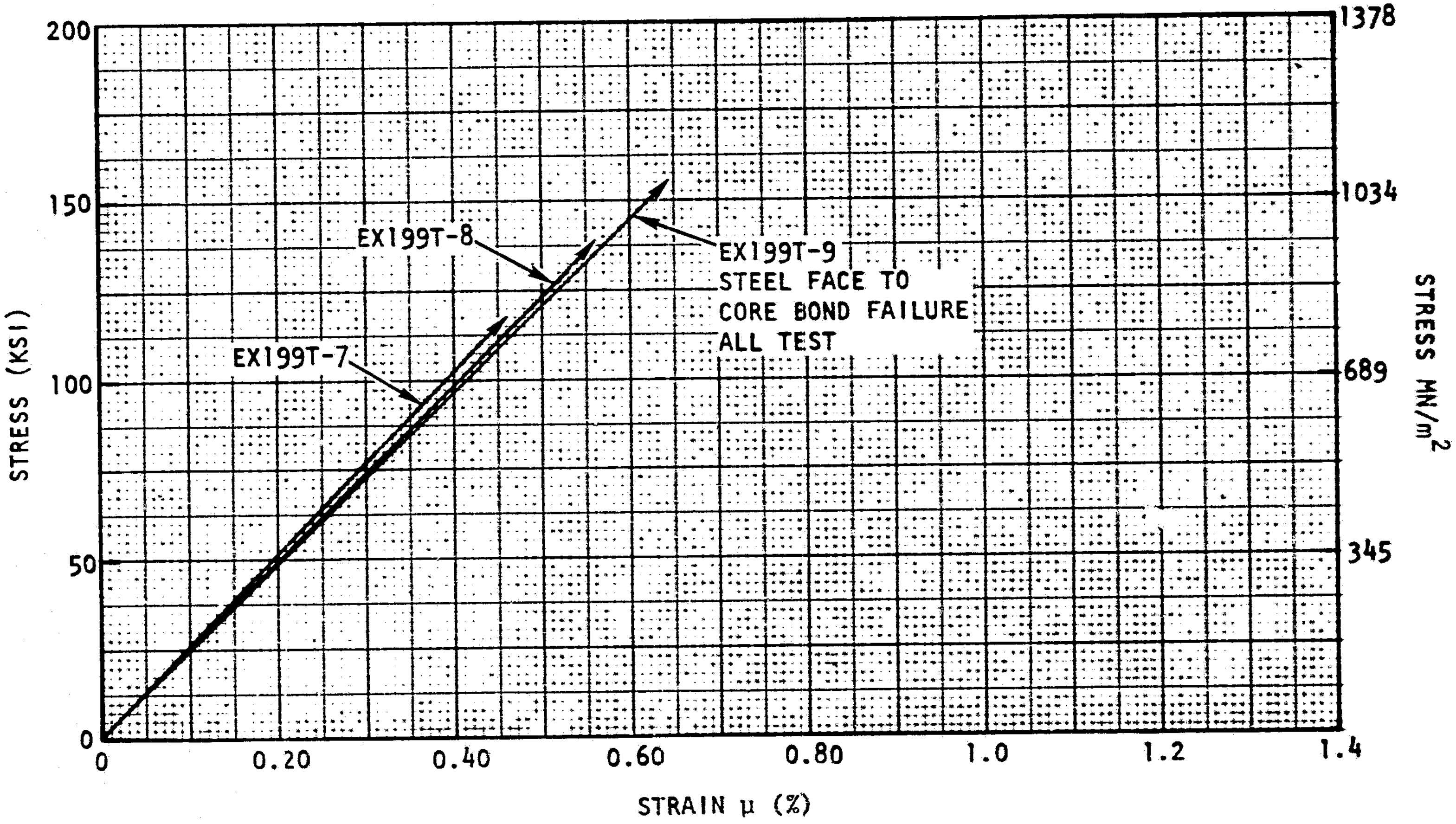

Figure B37. Tensile Stress/Strain Characteristics of $(0)_5$ Parallel Oriented LARC-160/Celion Laminates Aged for 125 Hours at 316 C (600 F), Beam Test at 316 C (600 F)

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COMPRESSION BEAM
CURVES

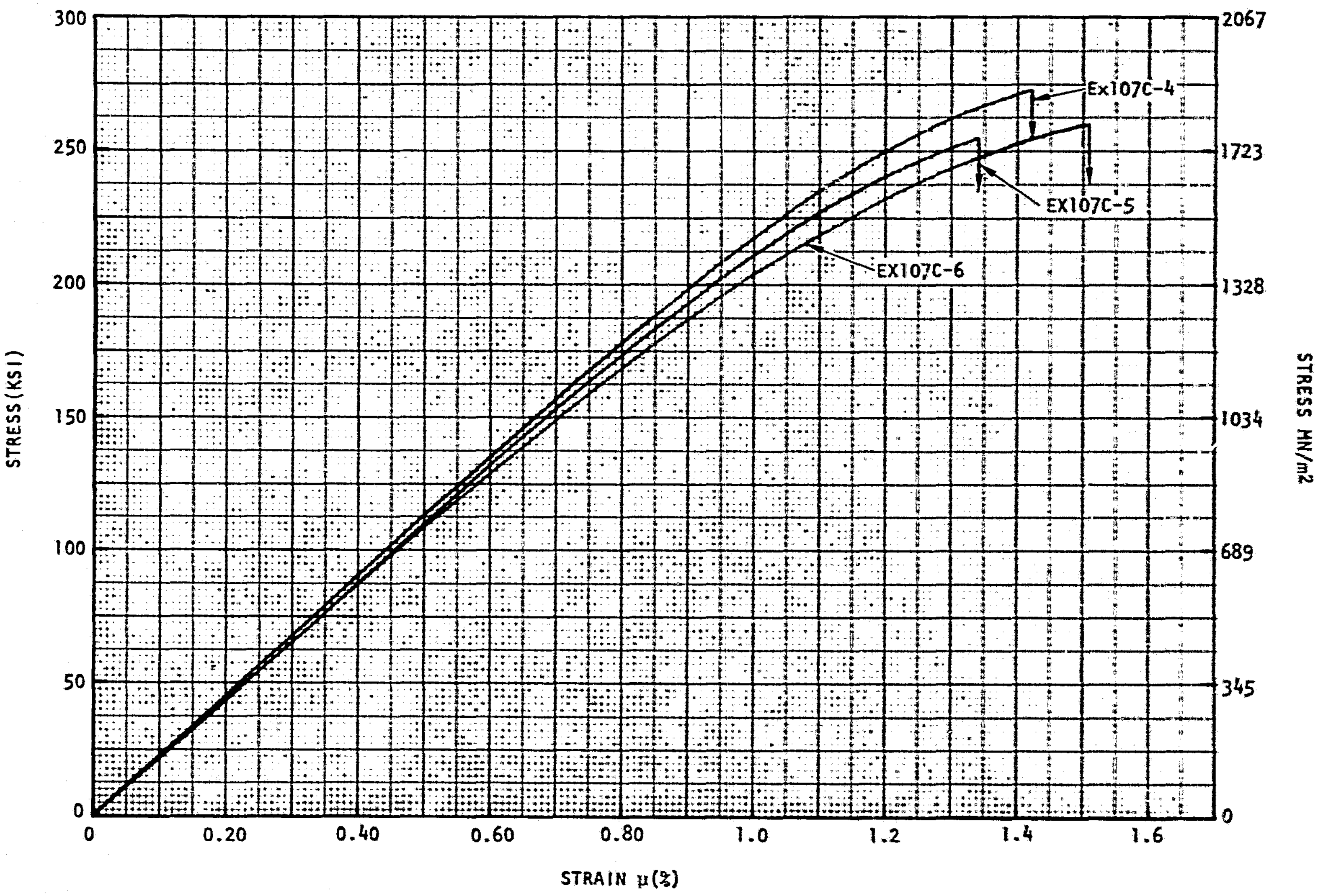

Figure B38. Compression Stress/Strain Characteristics of $(0)_5$ Parallel LARC-160/Celion Laminates at—132 C(−270 F)—Beam Test

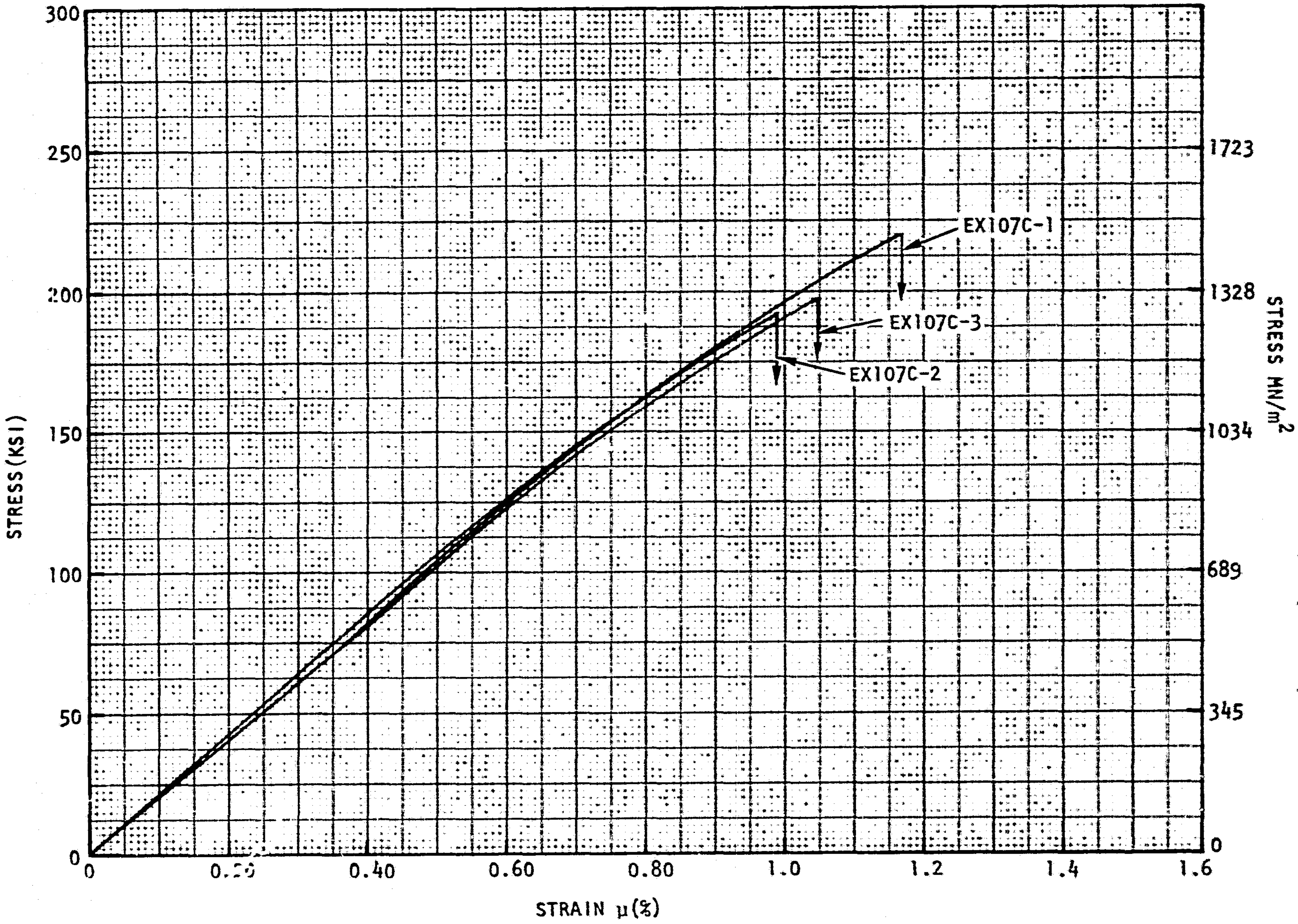

Figure B39. Compression Stress/Strain Characteristics of $(0)_5$ Parallel LARC-160/Celion Laminates at RT—Beam Test

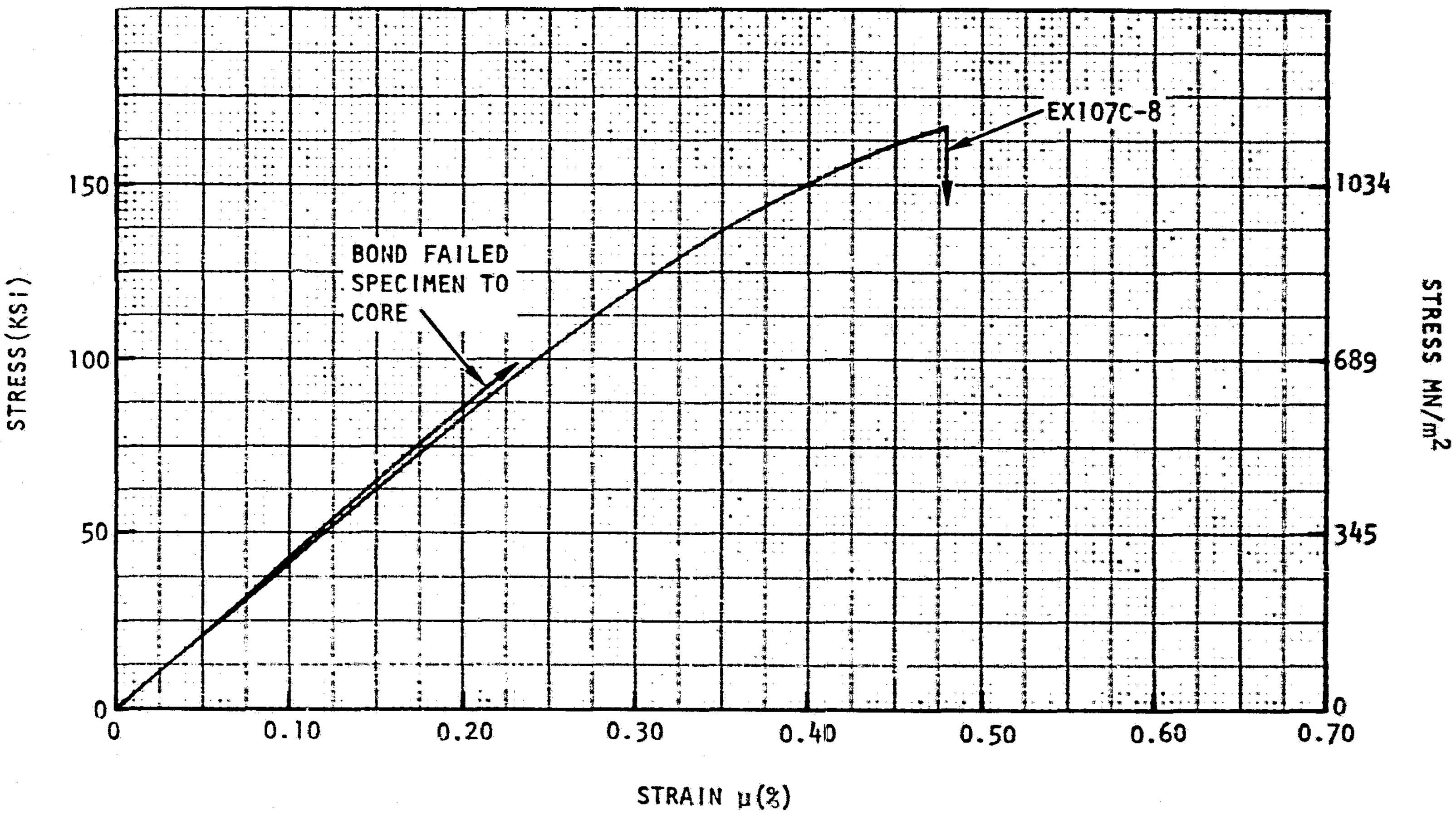

Figure B40. Compressive Stress/Strain Characteristics of (0)5 Parallel LARC-160/Celion Laminates at 204 C(400 F) Beam Test

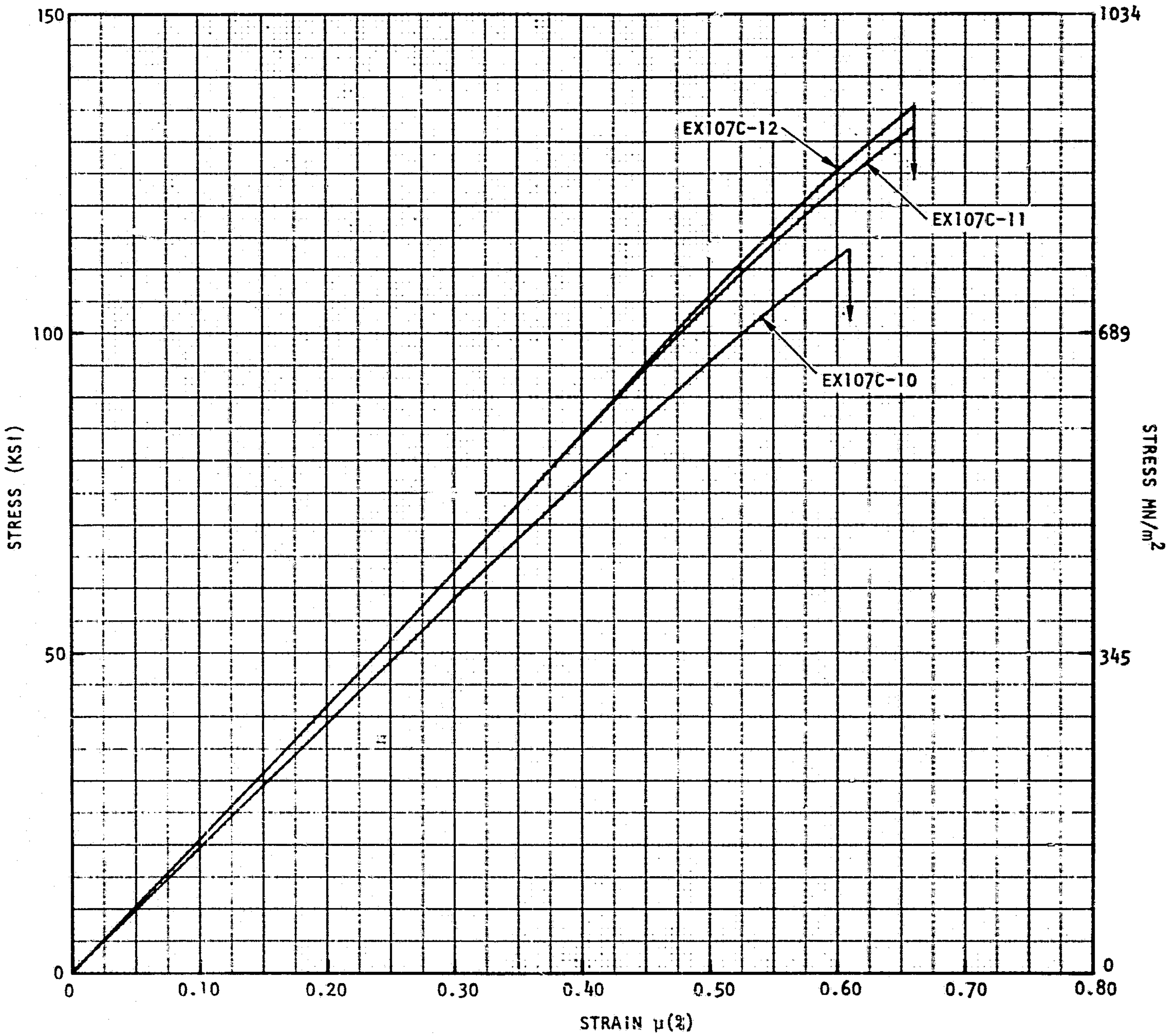

Figure B41. Compression Stress/Strain Characteristics of $(0)_5$ Parallel LARC-160/Celion Laminates at 316 C (600 F)—Beam Test

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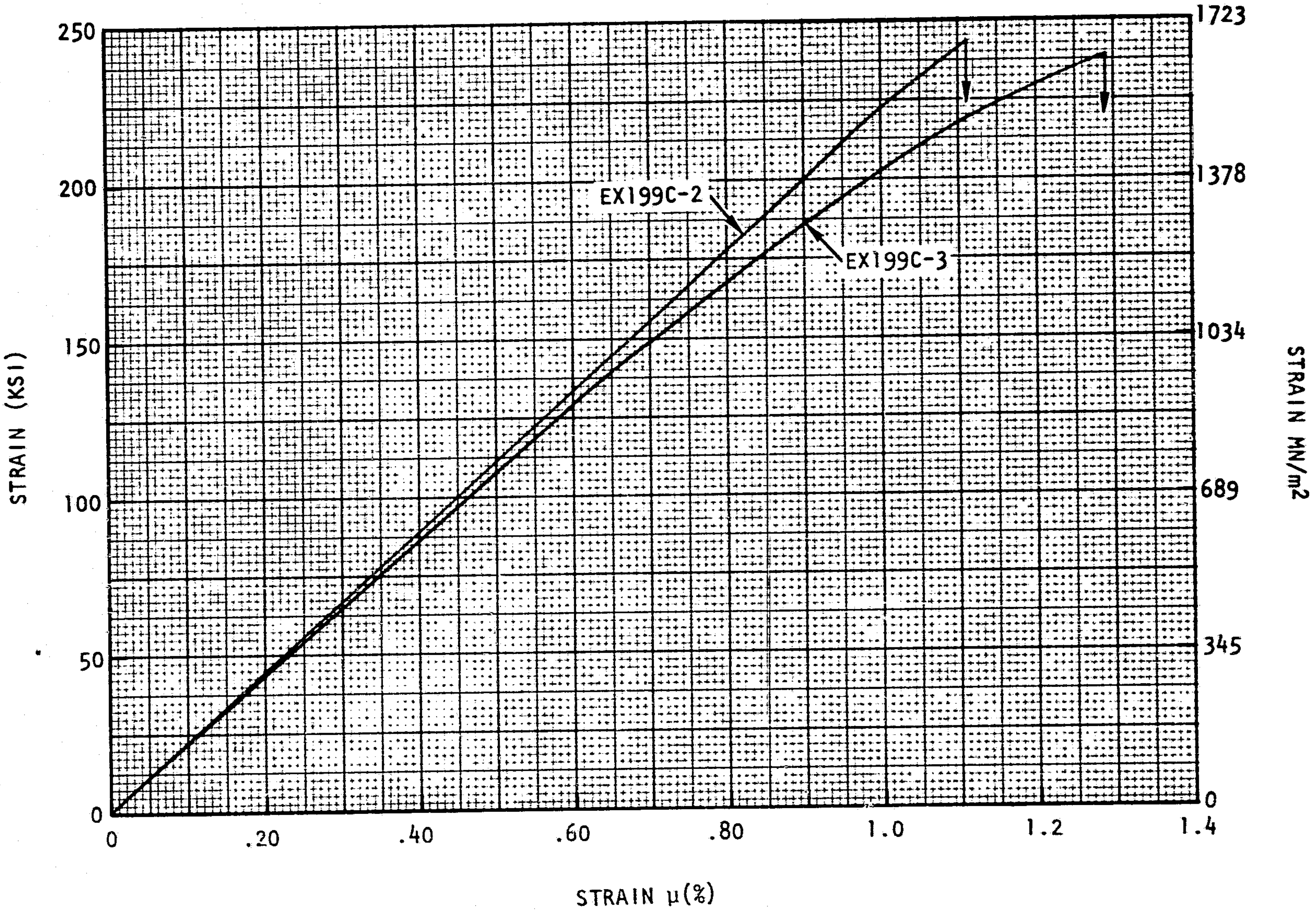

Figure B42. Compression Stress/Strain Characteristics of $(0)_5$, Parallel LARC-160/Celion Laminates aged 125 Hours at 316 C (600 F), Beam Test at - 132 C (-270 F)

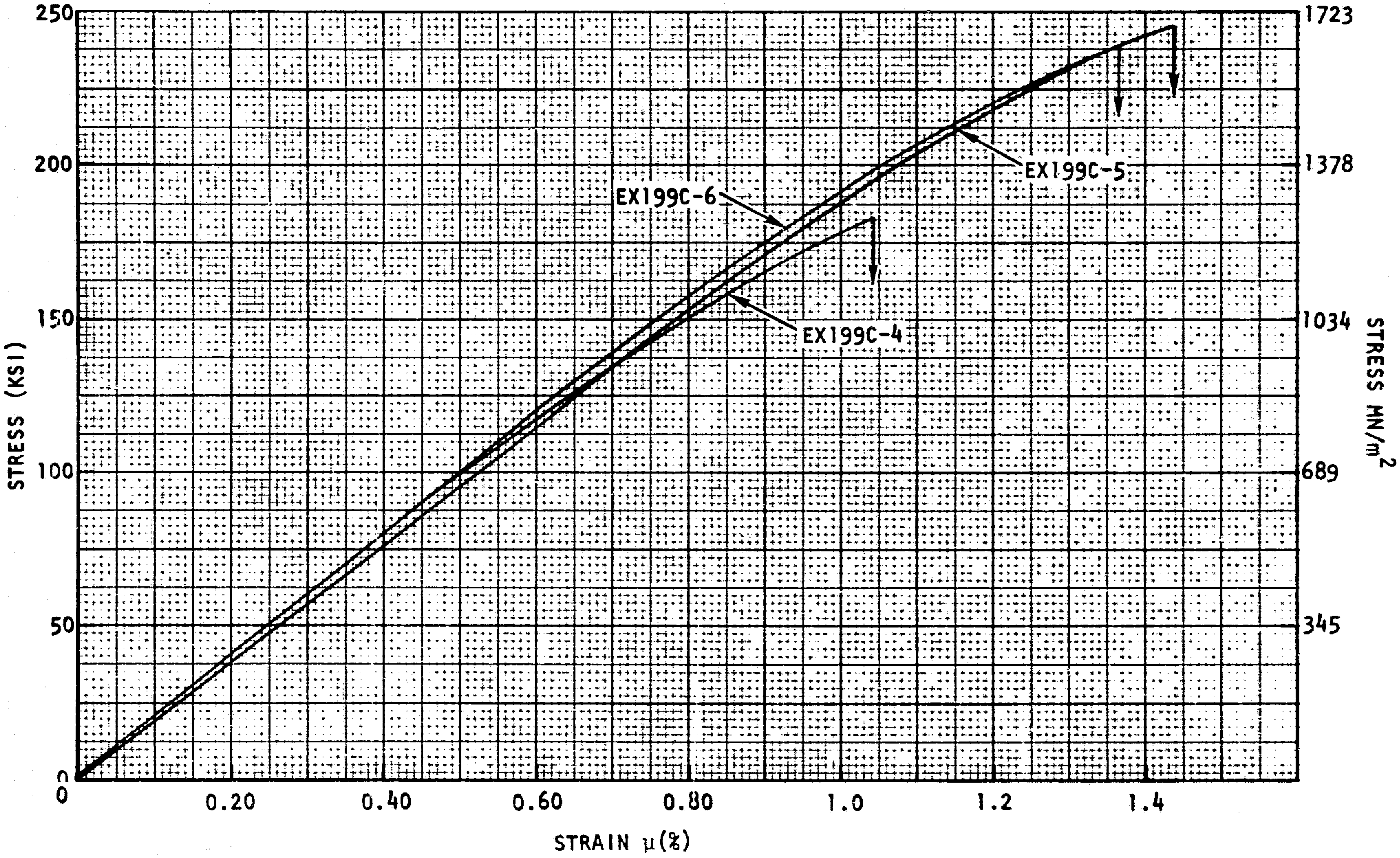

Figure B43 Compression Stress/Strain Characteristics of $(0)_5$, Parallel Oriented LARC-160/ Celion Laminates Aged 125 Hours at 316 C (600 F), Beam Test at RT

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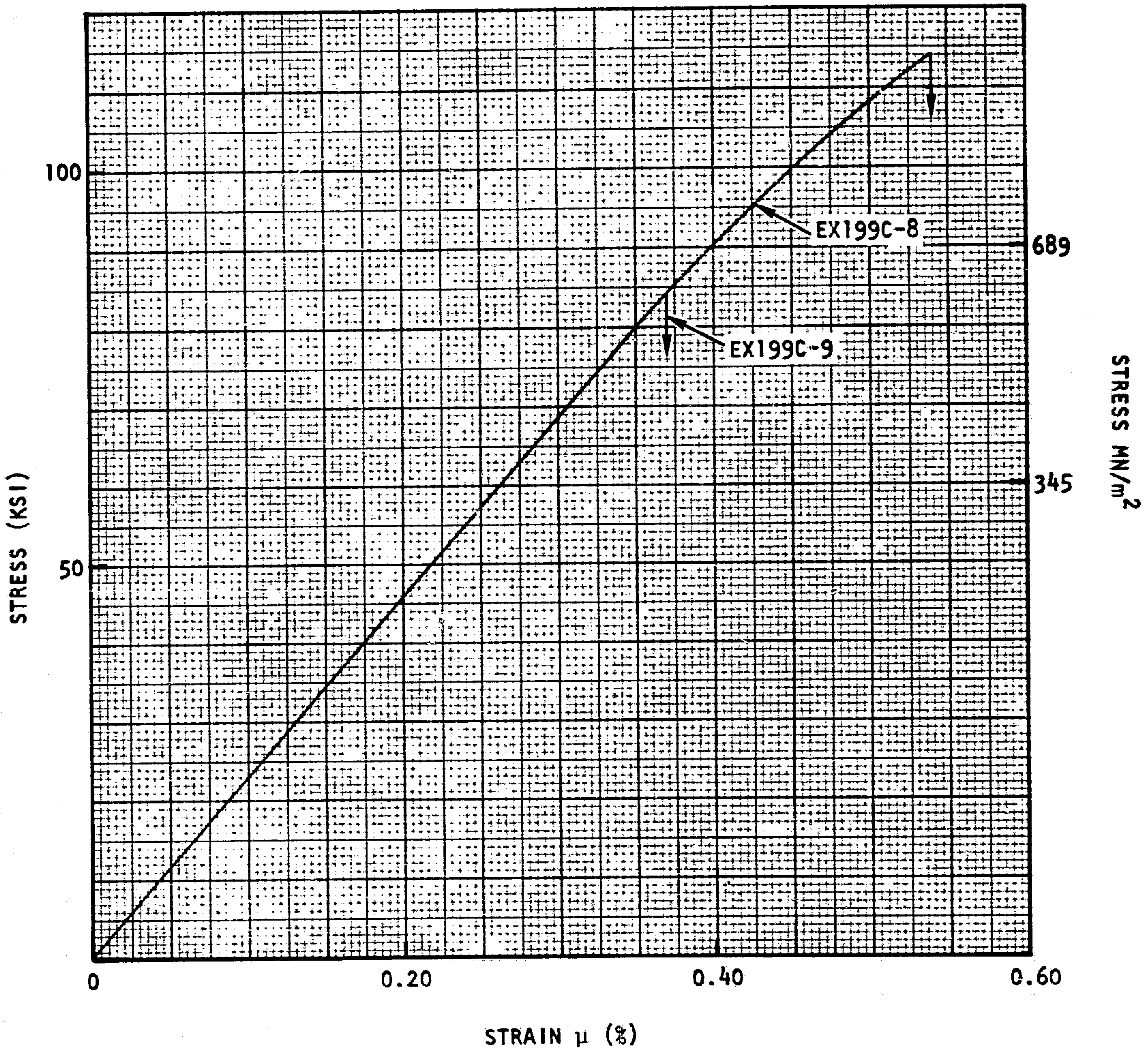

Figure B44 Compression Stress/Strain Characteristics of $(0)_5$ Parallel LARC160/ Laminates Aged for 125 Hours at 316 C (600 F) - Beam Test at 316 C (600 F)

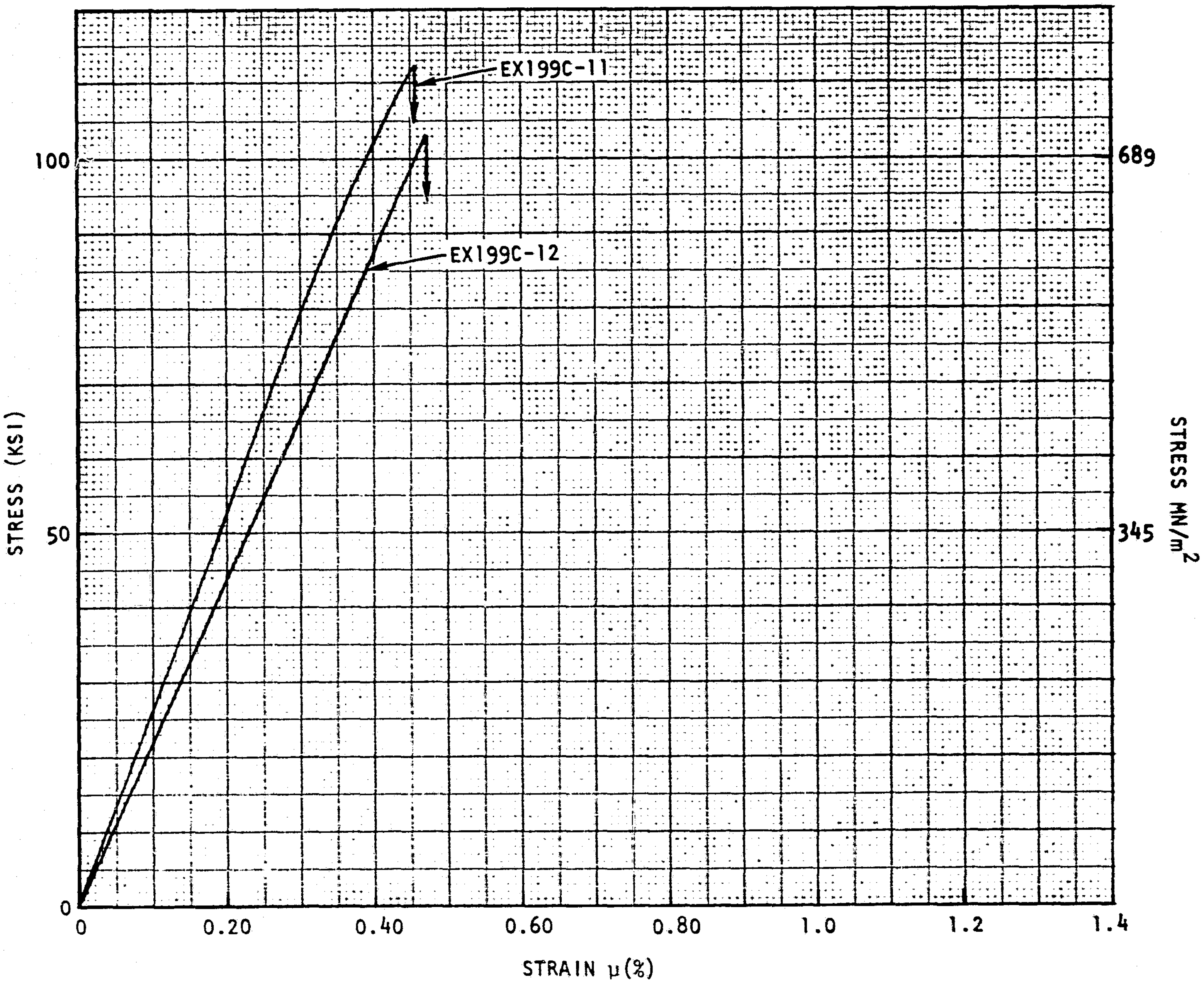

Figure B45 Compression Stress/Strain Characteristics of $(0)_5$, Parallel Oriented LARC-160/Celion Laminates Aged for 125 Hours at 316 C (600 F), Beam Test at 204 C (400 F)

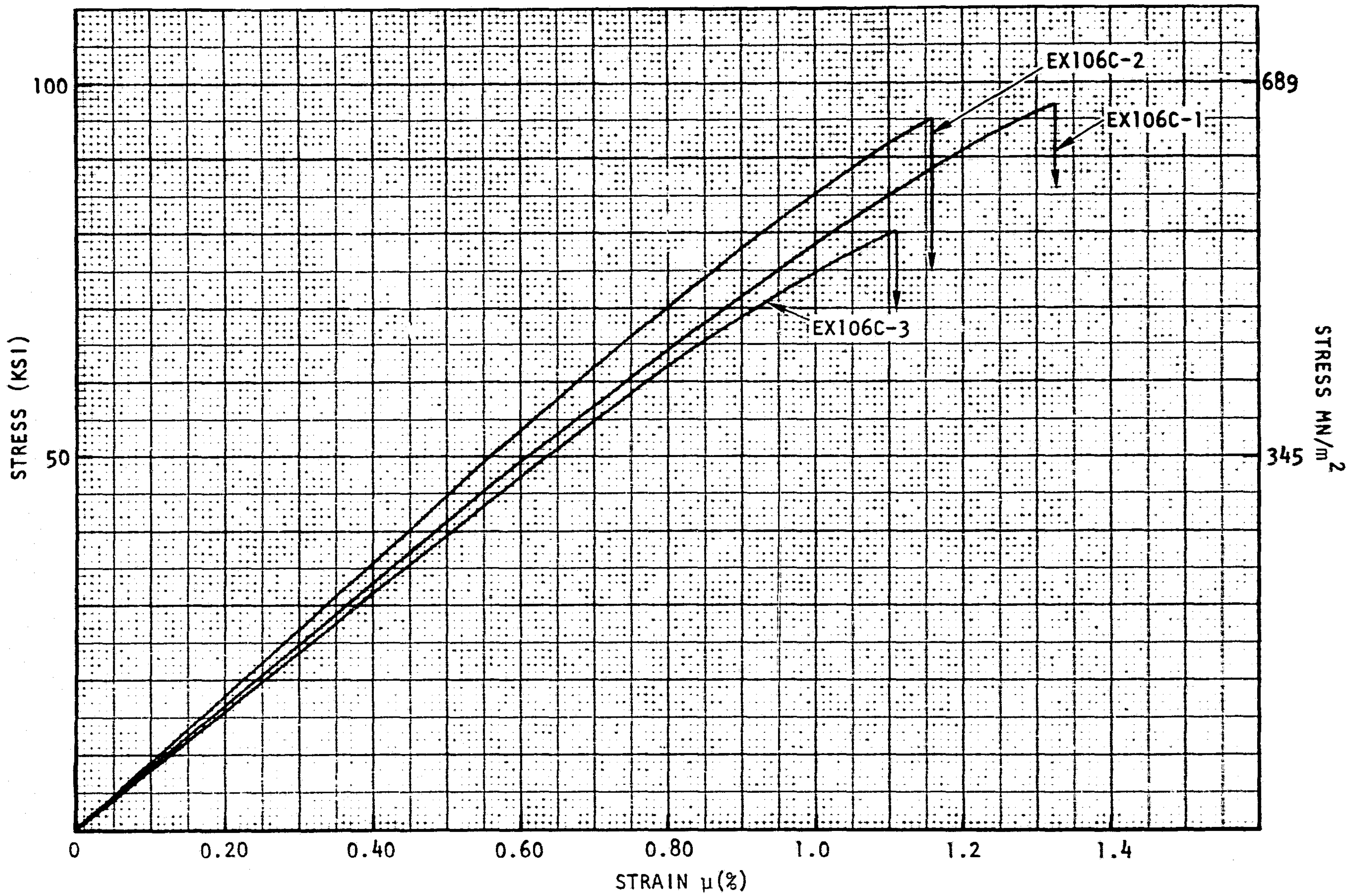

Figure B46 Compression Stress/Strain Characteristics of (0, $\pm$45, 90)$_S$ LARC-160/Celion Laminates at RT—Beam Test

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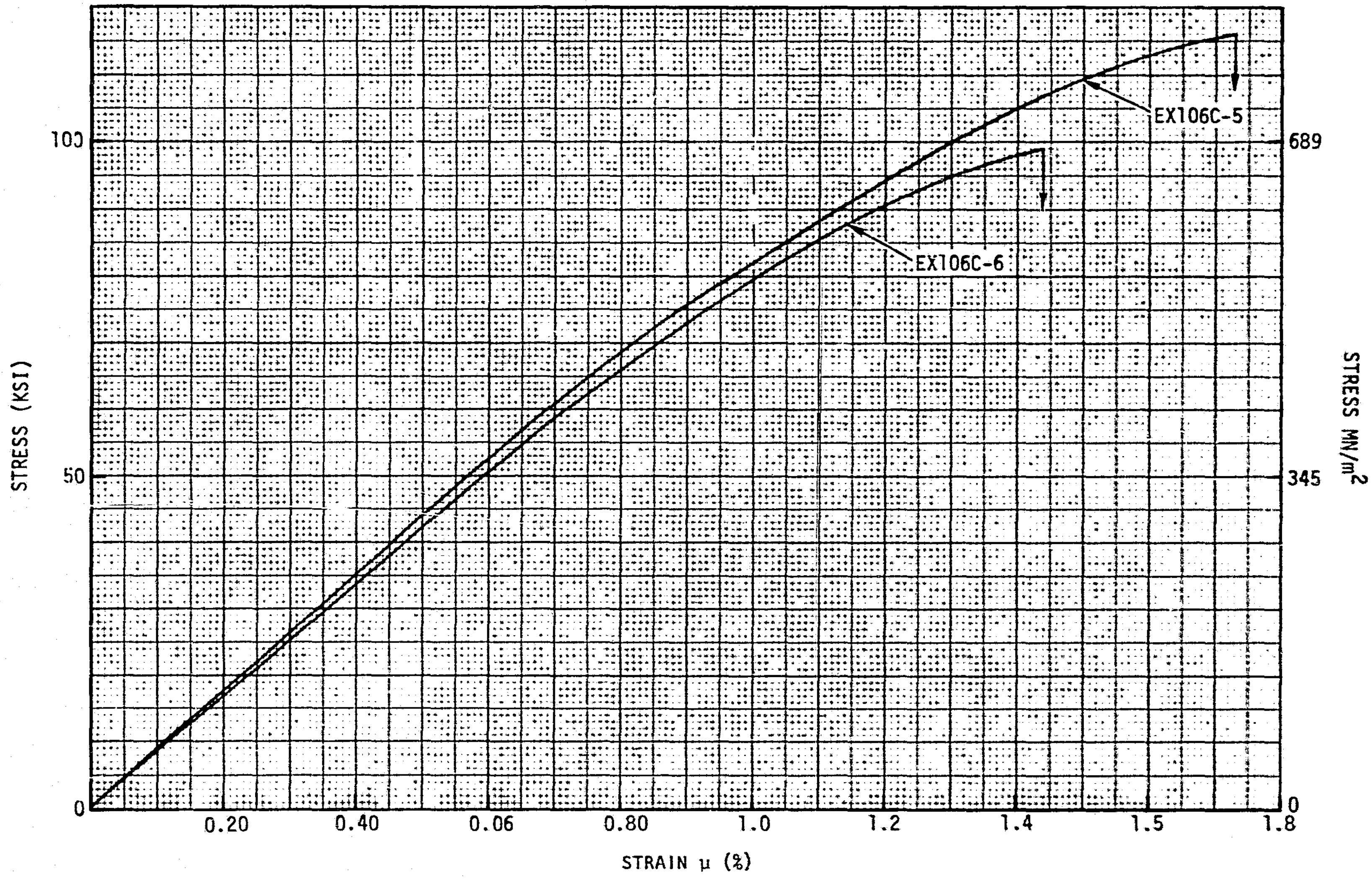

Figure B47 Compression Stress/Strain Characteristics of $(0,\underline{+}45,90)_S$ LARC-160/Celion Laminates at—132(-270 F)—Beam Test

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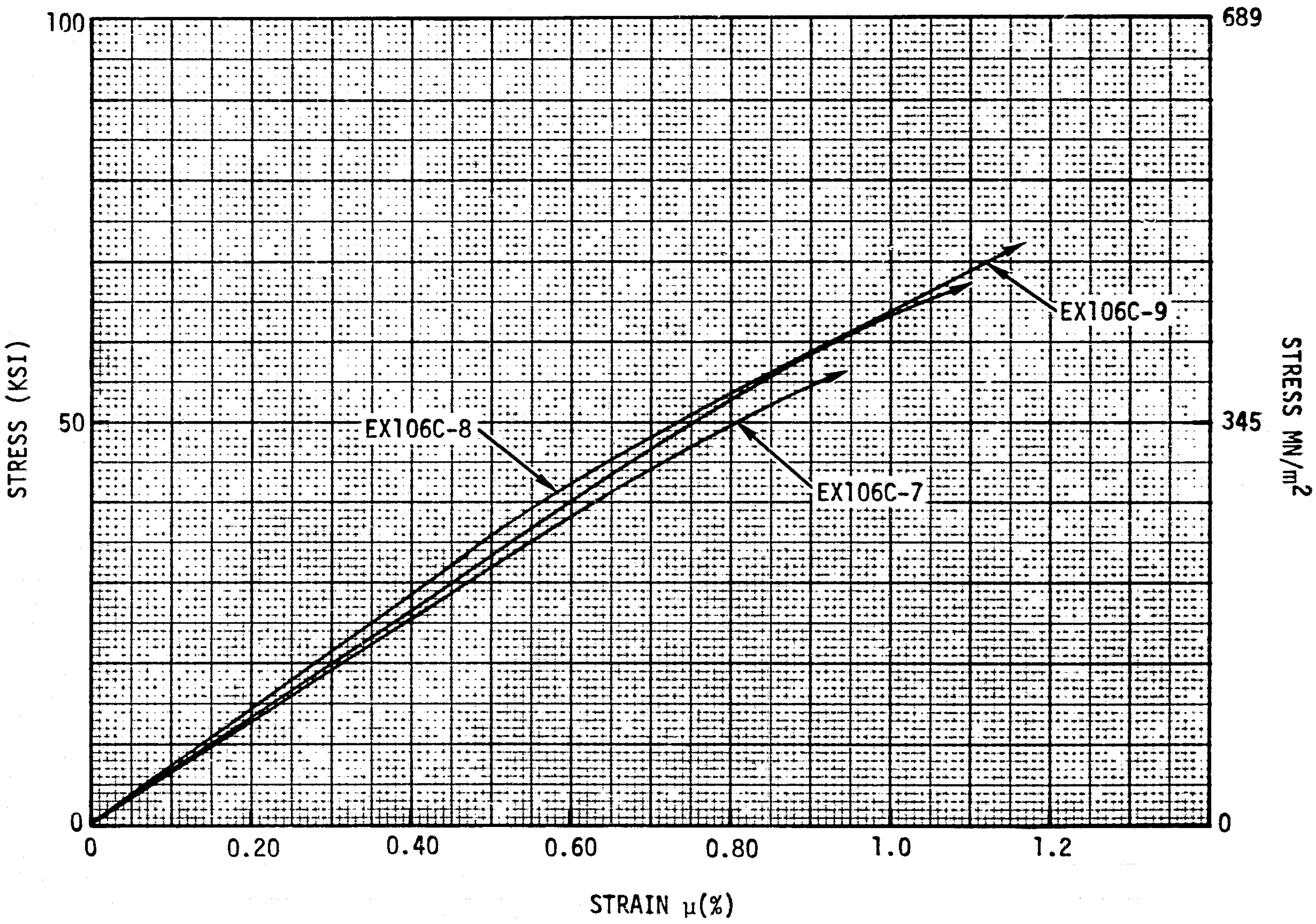

Figure B48 Compression Stress/Strain Characteristics of $(0,\pm45,90)_S$ LARC-160/Celion Laminates at 204 C (400 F)—Beam Test

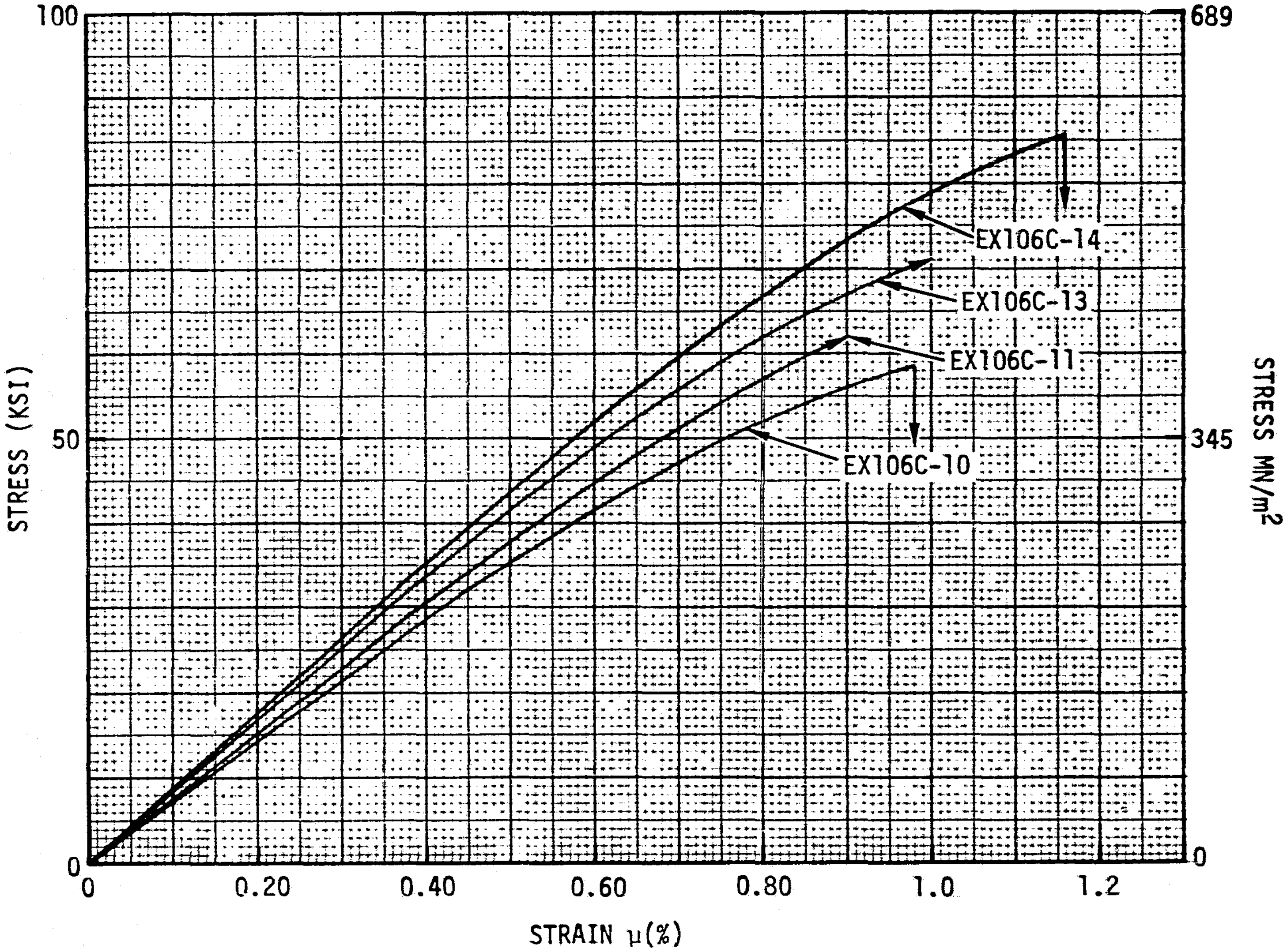

Figure B49 Compression Stress/Strain Characteristics of $(0,\pm45,90)_S$ LARC-160/Celion Laminates at 316 C (600 F)—Beam Test

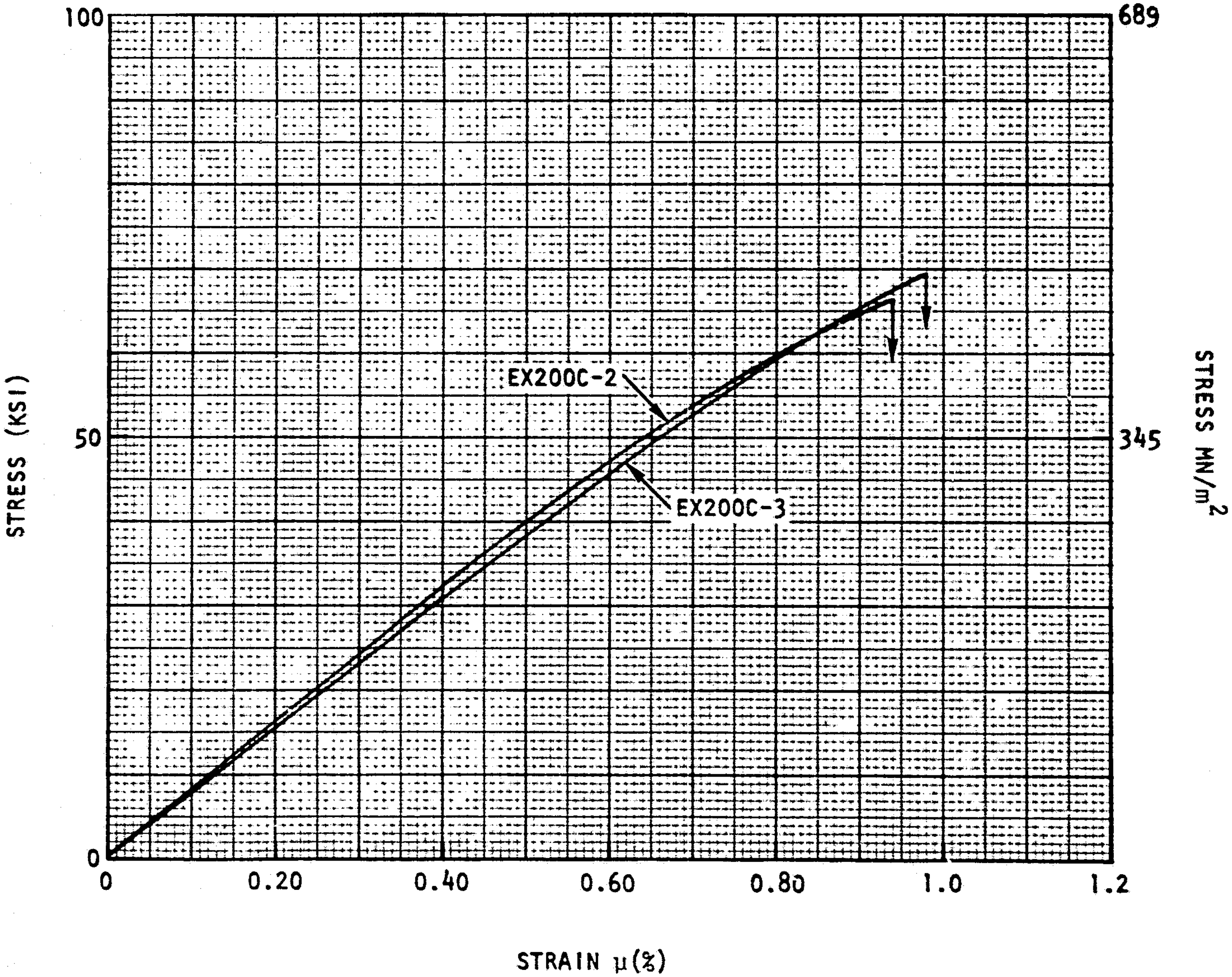

Figure B50 Compression Stress Strain Characteristics of (0, ±45, 90)$_S$ LARC-160/Celion Laminated Aged for 125 Hours at 316 C (600 F), Beam Test at -132 C (-270 F)

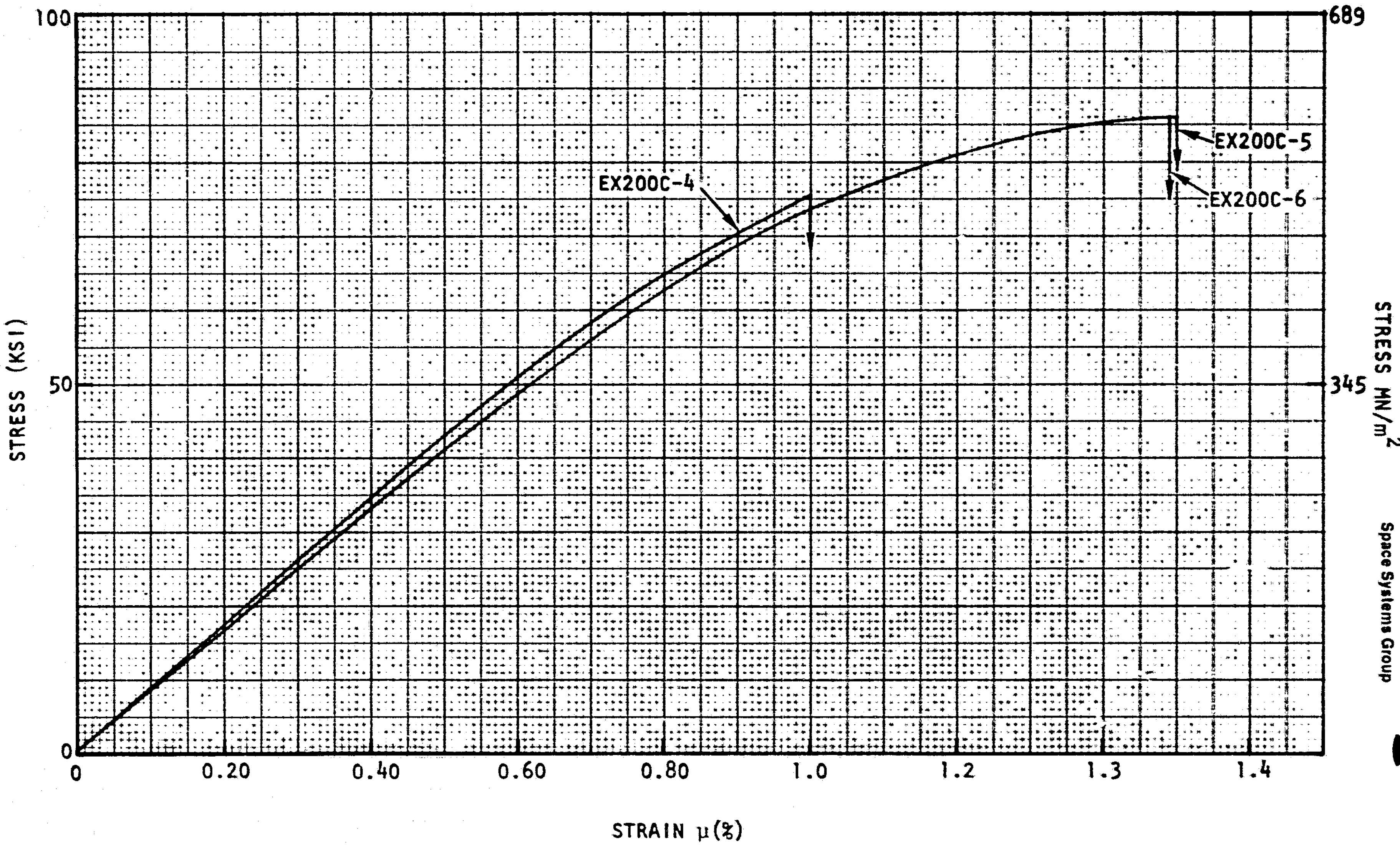

Figure B51 Compression Stress/Strain Characteristics of (0, ±45, 90)S LARC-160/Celion Laminates Aged for 125 Hours at 316 C (600 F) Beam Test at RT

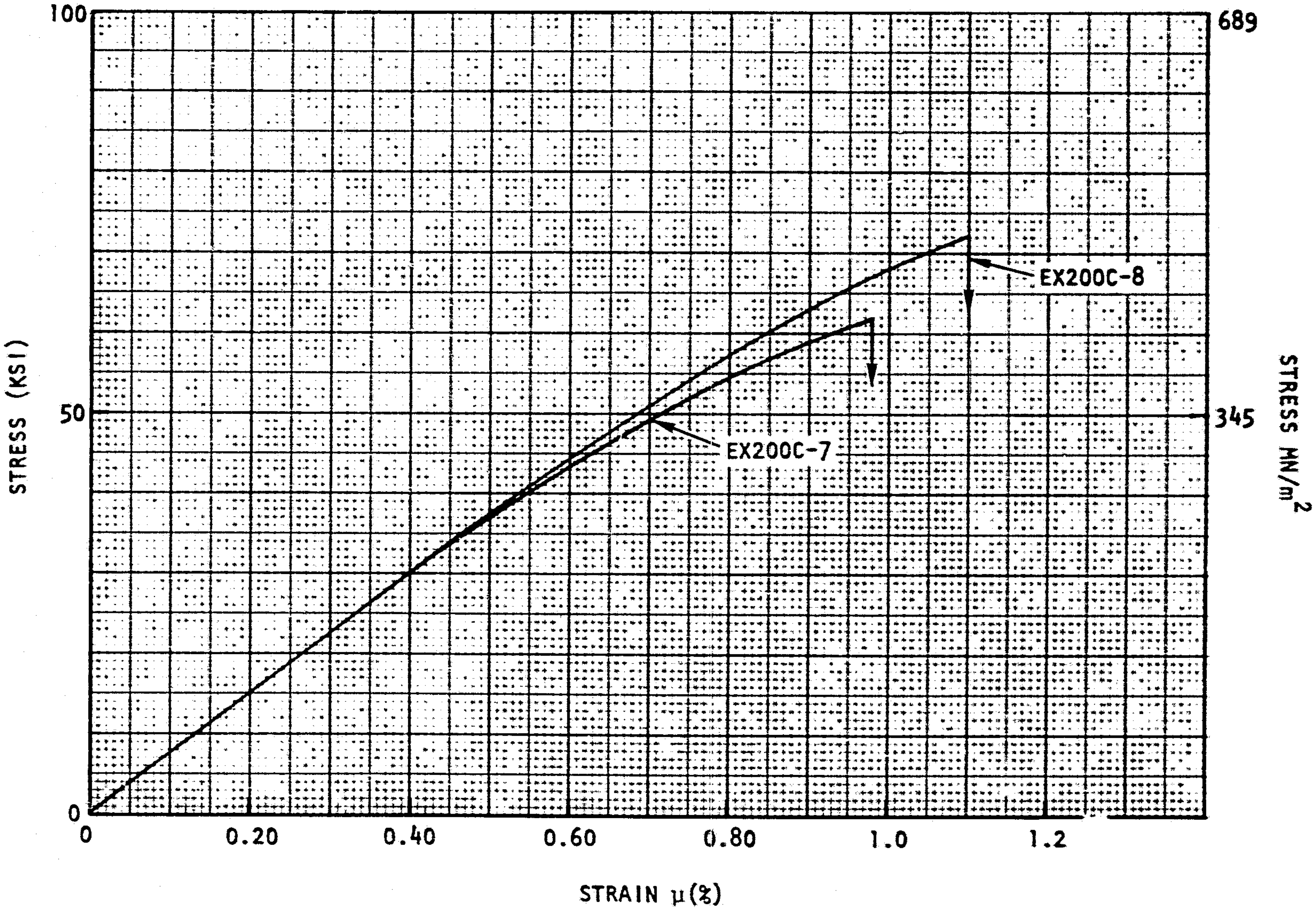

Figure B52 Compression Stress/Strain Characteristics of (0, ±45, 90)$_S$ LARC-160/Celion Laminates Aged for 125 Hours at 316 C (600 F), Beam Test at 316 C (600 F)

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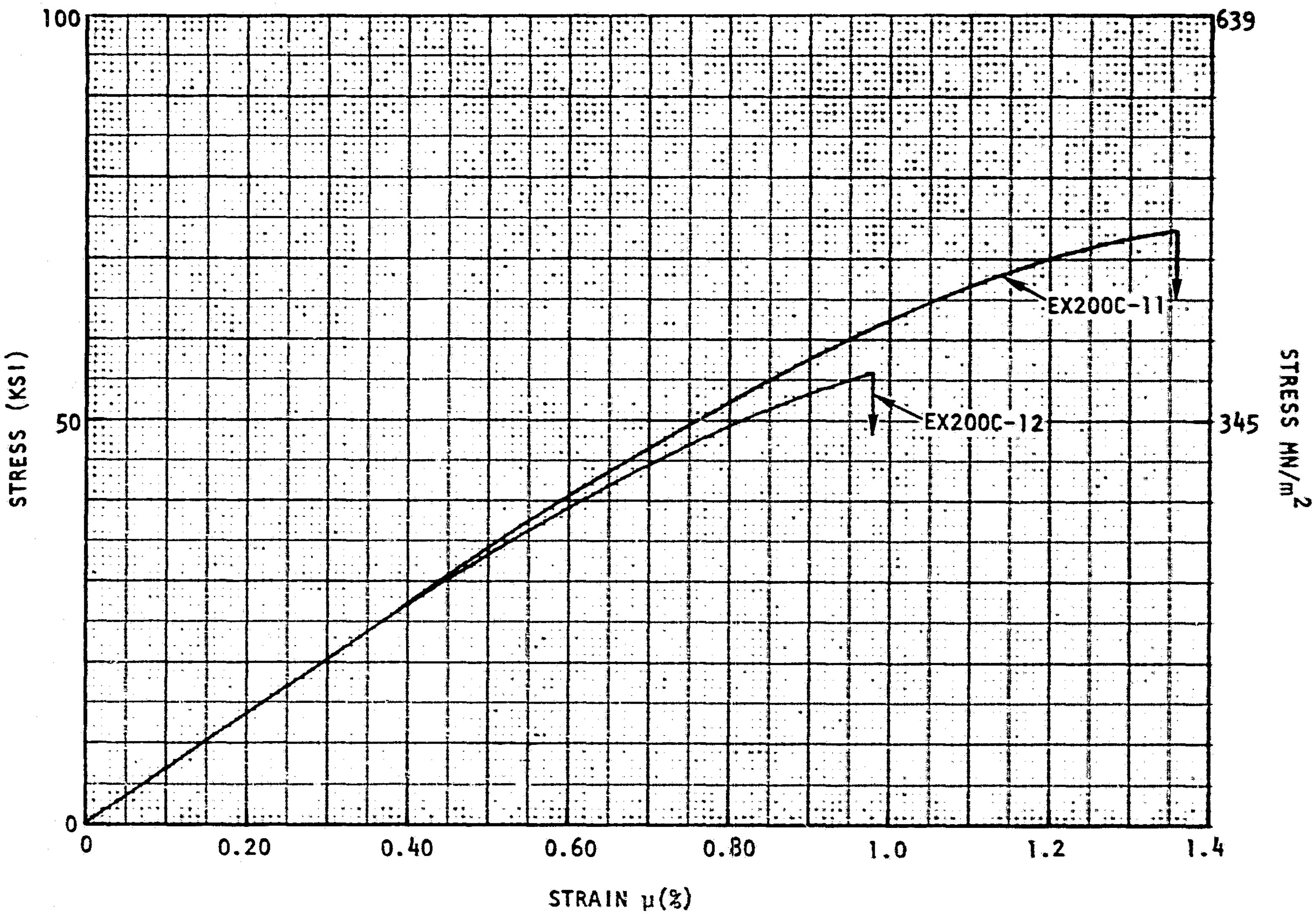

Figure B53 Compression Stress/Strain Characteristics of (0, $\pm$45, 90)$_S$ LARC-160/Celion Laminates Aged for 125 Hours at 316 C (600 F), Beam Test at 204 C (400 F)